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OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA.

FOR THE

PROMOTION OF THE MECHANIC ARTS.

VOL. LXVII.] APRIL, 1874. No. 4.

EDITORIAL.

ITEMS AND NOVELTIES.

Shaw's Relief Block for Rolling Mills.—At the last meeting of the Institute, Mr. Thomas Shaw, of Philadelphia, presented the improved mechanism, of which he gave the following description:

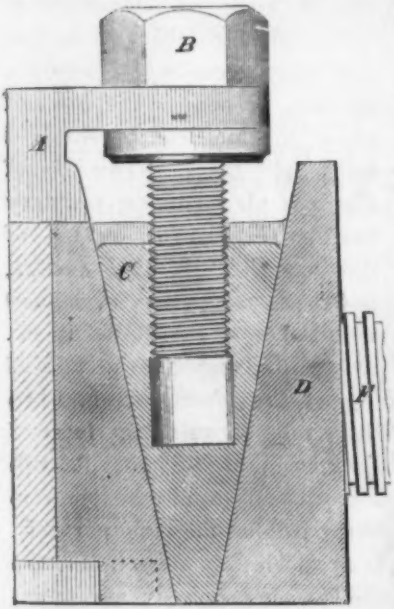


Fig. 1.

The invention, which is herewith illustrated, is designed to prevent the breaking of housings, rolls, and other gearing pertaining to rolling mills, and to afford instant relief when the engine is overloaded. In order to fulfil the object mentioned, the demands made upon the invention are peculiar, for it will be observed that the power of a rolling mill is a thing not to be trifled with, that no elasticity is permissable, that the adjustment should be under perfect control, and not liable to disorder when adjusted, and that the parts should be so arranged that the operator will be enabled

to release a load of 500 to 1,000 tons with an ordinary bar wrench, when emergency requires.

All of the foregoing points are met in Mr. Shaw's Relief Block, which consists of an obtuse wedge C (Fig. 1.), supported on the top of its bed-plate *A*, of corresponding angle. The said bed-plate terminates in a flange on its outer end for the reception of the collars of screw *B*, which screw is tapped in to base of wedge *C*, and controls the movements of the same. The wedge *C* is covered by a top plate *D*, having side wings, as shown in (Fig 2), reaching down to plate *A*, to prevent any lateral movement of the three separate parts. The angles of wedge *C* are made sufficiently obtuse to cause the wedge to be squeezed outward whenever pressure is applied, but the angle should be so acute as not to give any great force to this outward tendency. This angle will vary with the material employed in its construction ; with steel, three inches to the foot being a sufficient angle for each side of wedge *C*. Whenever it is desired to withdraw the wedge, it is only necessary to apply a spanner wrench to the head of screw *B*, which can be revolved under all loads. This Relief Block is placed in an ordinary housing *G* (Fig. 3), on top of the journals of rolls *I* and *H*, and the housing screw *F*, pressed upon the top of said Relief Block.

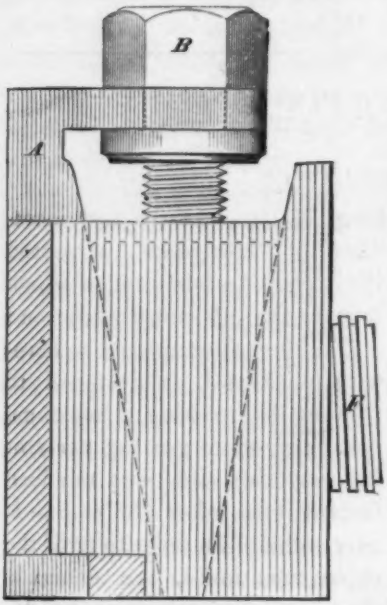


Fig. 2.

It will be observed how easily this invention accomplishes its task of relieving the screw, rolls, and housings of the severe strain, when metal is caught and locked between the rolls, by using the force of the strain between the journals to eject an obtuse wedge at the will of the operator. The Relief Block is perfectly solid and free from all elasticity, (unlike hydraulic presses tried for the same purpose), and will always maintain the height at which they are set, and can be used for slight adjustments of the rolls when required ; and by introducing them, it will no longer be necessary for rolling mill owners

to place engines of 50 to 70 per cent. of excess of power, to crowd through the rolls whatever may be placed between them without regard to the strength of rolls and housings, to the imminent risk of breaking and damaging expensive machinery.

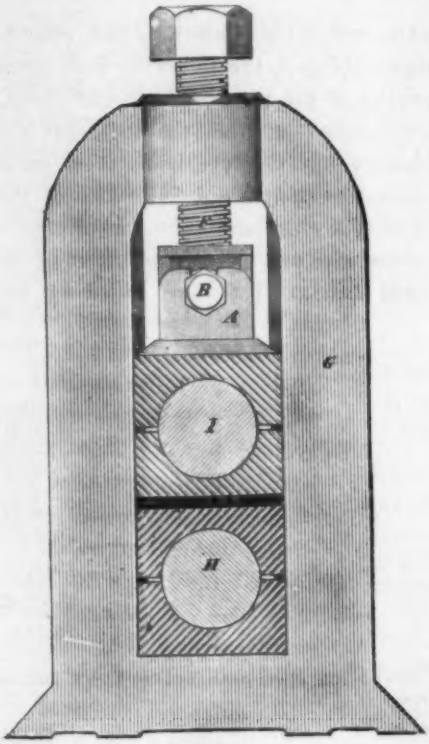


Fig. 3.

All machinery liable to excessive strains should have a limit of safety before its maximum strength is reached. In rolling mills, this engine is the best safety-valve for overstrain, which should be so proportioned with steam, as to stop the engine before breaking the machinery.

There need be no fear of the engine slacking up under ordinary work, for the damaging strain is from 50 to 100 per cent. in excess of ordinary loads. Whenever the engine slacks speed from excessive strain, liable to break the machinery, instant relief can be afforded by the Relief Block here described.

Coal-cutting Machinery.*—An exhaustive treatment of the subject of coal-cutting by machinery, and its probable influence on the future of coal mining industry, was lately had before the Cleveland Institute of Engineers, Middlesbrough, England. The conclusions derived from this discussion are stated to have been taken from the best results of the best machines yet invented. This distinction seems to have been accorded without dispute to the so-called Gartsherrie coal-cutter of the Messrs. Baird, which has been in operation constantly at several large collieries ever since its first introduction, some six or seven years ago. The advantages claimed for this machine are:—1, a diminished cost of production; 2, an improved ven-

* American Exchange and Review, April, 1874.

tilation; 3, a reduction of waste; and 4, a relief to the miner from the hardest part of his toil.

In consideration of the extent to which the conditions just enumerated are fulfilled by coal-cutting machinery, the following data were brought out, concerning the working of the machine here mentioned. The data are, however, necessarily imperfect, from the fact that the application of coal-cutting machinery has not yet been tried on a scale sufficiently extensive and complete to give a definite idea of the minimum cost of production. The following tabulation, based on the result of a year's working, gives the cost and the number of men required to remove 120 yards of coal (equal to 130 tons) holed by the Gartsherrie coal-cutter:—

		Cost.	
No. of Men.		*s.*	*d.*
24	Hewers (per ton), . .	1	5
8	Deputies " . . .	0	5
6	Putters " . . .	0	2½
6	Men at cutters, . . .	0	3¾
3	Brake and foremen, . .	0	1¾
2	Men repairing cutter chain, .	0	1¼
49		2	7¼

To get the same quantity of coal from the same colliery by hand-labor would require:—

		Cost.	
No. of Men.		*s.*	*d.*
67	Hewers (per ton), . .	3	3
6	Putters " . . .	0	2½
6	Deputies " . .	0	3¾
79		3	9¼

Showing a difference in favor of the coal-cutter of 1*s.* 2*d.* per ton.

At another colliery, the cost of doing the same work is estimated at 3*s.* 1¾*d.* per ton, an increase which is attributed to the comparative thinness of the seam (two feet six inches.) Taking, however, the best performance of the coal-cutter as a basis of calculation, and extending its economical showing over the total production of the United Kingdom, the fact is demonstrated that if coal-cutting machinery were universally adopted, there would be an economy of at least £6,000,000 effected in raising the 120,000,000 tons of coal now annually produced in the United Kingdom.

With regard to the subject of the extent to which the introduction of coal-cutting machinery will reduce the number of colliery operatives, which is an important phase of the question, it is estimated that the force now employed in the aforesaid production (418,088) could be reduced to at least 200,000. The substitution of machine for hand labor will, in every probability, be so slow as to make no serious disturbance in the employment of colliers, while the increase of production will probably be so unprecentedly large within the next decade as to require the labor of all at present employed.

With respect to the reduction of waste, it is declared that the total loss from this cause, with the Gartsherrie machine, is about 5 per cent., or 15 per cent. less than the average proportion of waste by hand hewing,

The relief of the miner from the hardest portion of his toil is advanced as a recommendation, which, from a humanitarian standpoint, should lead to the universal adoption of coal cutting machinery. It is argued, and with truth, that workmen frequently throw needless and vexatious difficulties in the way of employers who seek to introduce improved processes and appliances. In this case, however, any objection from the workmen would seem to be unreasonable and short-sighted. The hardest work devolving on the miner, with the machine cutter, is mere child's play compared with the hand hewing.

In how far the foregoing arguments may apply to American coal-mining industry, it is not easy to say; inasmuch as the condition of things here is very different. We know of but one case where coal-cutting machinery has been employed, namely in the block-coal fields of Indiana, already referred to in a former issue of the *Journal*, and in that, the verdict which it has commanded is a favorable one. It has been found, however, that the economy of such machines is most evident where the seams worked are of moderate thickness; and their introduction into our anthracite mines, where the seams are often of enormous dimensions, is a very improbable contingency, for the present at least. In England, however, the subject has assumed important proportions, as may be drawn not only from the extent to which such machinery has been introduced, but from the following closing remarks of an eminent speaker before the Cleveland Institute of Engineers:

"England's future prosperity must, to a large extent, depend upon her mineral resources, and these mineral resources will be largely affected by coal cutting machinery. The experience of the past two

years has amply proved that any restriction of, or interference with our coal supply is sufficient to disorganize all the springs of industry, and entail more or less of hardship, mischief and inconvenience on every class of the community. I do not think, then, that I have at all exaggerated the importance of coal-cutting machinery in reference to the coal trade; nor shall I greatly err in predicting that in the not far distant future it will become to the miners and mine owners the question of questions, and receive much more consideration than it has ever done in the past."—W. H. W.

Baker's Rotary Blower.—At the last meeting of the Institute, there was presented for exhibition and described, the apparatus above-named, of which we herewith append external and sectional views:

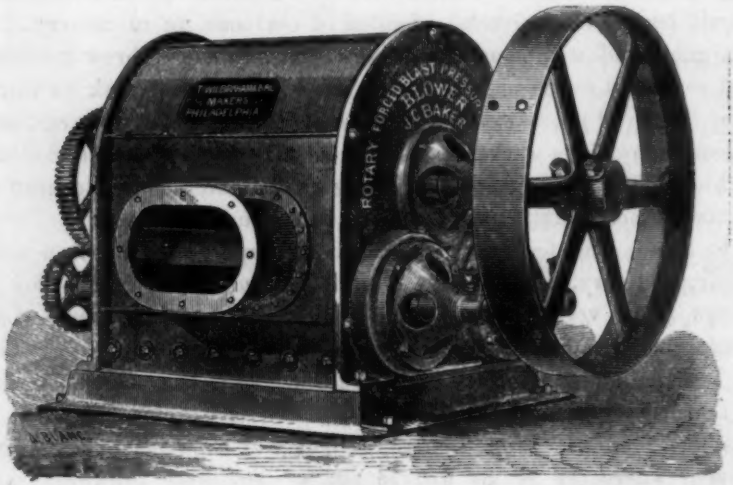


Fig. 1.

From an inspection of the engravings, the mechanism and operation of the machine will be evident; the sectional view (fig. 2), showing both its construction and the direction of the currents produced.

The following details will, however, sufficiently explain the invention: The external case of the blower is made of light boiler iron, formed up very truly and inserted slightly into the heads of the machine, said heads being made of cast-iron and faced off truly, and firmly secured to a substantial cast-iron bed plate; the two heads are

bolted together longitudinally by iron rods on the outside of the case; the drum concentric with the case, as well as the two lower drums, are each one solid iron casting and are all turned as true as possible; the two lower drums only act as abutments alternately; the opening in their sides is to allow free passage for the wings of the central drum. The gearing on the exterior of blower is for the purpose of retaining each drum in its proper position; a wire guard or screen is attached to the inlet to prevent anything from entering that might cause injury to the internal movements of the blower. The semi-annular space above the central drum is the chamber from which the air is expelled by the wings of the central drum in its revolutions; this space, as it may be seen by the cut, is a section of a ring at all points of equal radius and area, and as the wings of the central drum continue to revolve at the same velocity, the air must be expelled in a nearly continuous stream.

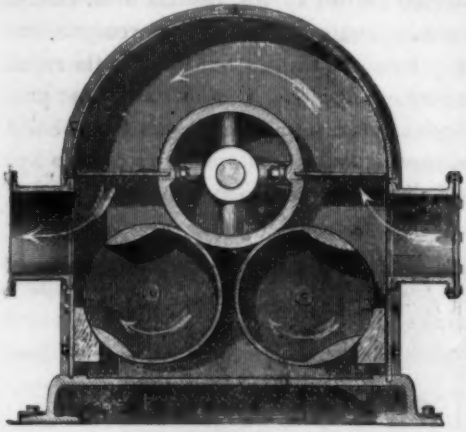
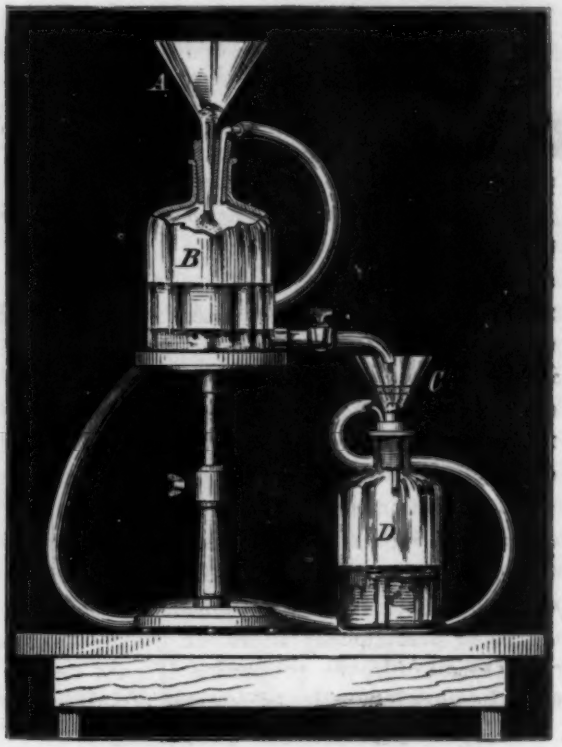


Fig. 2.

It is claimed for this blower, amongst other things, that it will give a steadier blast than any other thus far produced, and that it is likewise quite superior in point of strength, fewness of parts, ease of motion, and durability.

Horse-Power of Steam Boilers.—We take pleasure in informing steam boiler makers and users, and the engineering public generally, that the various reports of the committee of this Institute, on the Horse-Power of Steam Boilers, together with the discussion on the same, have been published in pamphlet form, and will be found of value to those interested in the subject. A limited number are for sale at the Institute at 50 cents each, to pay for publication.

On the Purification of Mercury.—By Prof. Albert R. Leeds.—In investigations carried on in physical laboratories, and in the volumetric analysis of gases, a large quantity of mercury is employed, and as it is very readily contaminated, a method for its rapid and convenient purification is important. Such a method must provide for the removal of the three kind of impurities which are usually present: First, foreign metals, especially lead, zinc, and tin; secondly, common dirt and dust; and thirdly, water or other liquids.



The most convenient device hitherto employed was a long glass tube, into which the mercury was poured through a paper funnel, the funnel having a pin hole at the bottom, and serving to retain the dirt and dust. The tube was partly filled with dilute nitric acid, and was provided with a stop cock below, or with a bent tube, so that a short column of mercury might balance a long column of acid.

The device herein recommended consists of a glass funnel, *A*, ca-

pable of holding five or ten pounds of mercury, the tube of which is cut off at a point just below the stopper of the bottle, *B*. Cotton wool is jammed into the tube until it fills up the neck, and bulges out at the bottom of the funnel. A short glass tube bent at right angles passes likewise through the india rubber stopper, and is connected with a water air pump. The bottle is two-thirds filled with dilute nitric acid, (one part of acid and four or five parts of water). The impure mercury poured into the funnel, *A*, is drawn through the cotton plug in a multitude of streams, and passes as a fine rain through the acid below. The foreign metals, if not in too large quantities, are removed by solution in the acid, and the pure mercury collects below. It is then run off through the stop cock into a second funnel *C;* and, after being thoroughly dried by suction through another plug of cotton wool, it is caught and preserved in the bottle, *D*. A short time suffices for the almost automatic purification of a large quantity of mercury.—*From the Scientific American. Stevens' Institute of Technology, February*, 1874.

Comparative Value of Artificial Alizarine and Madder.—The growing importance of the manufacture of artificial alizarine has several times of late been referred to in the *Journal*, as well as the probable effect of this increase on the cultivation of the madder. To such proportions has the alizarine manufacture attained, that the prevailing opinion has been to the effect that the near future would witness the total extinction of the madder culture.

In a recent report, however, of the Société Industrielle de Mulhouse, a somewhat different view is taken from that generally held.

The report maintains that the large demand for artificial alizarine will not seriously or permanently affect the normal consumption of madder; or, in other words, the proportion of pure madder used in the arts, before the introduction into commerce of extracts of madder, will remain unchanged. The artificial alizarine comes into competition with these extracts, but only to a limited extent; for it is declared that, while the violet shades which it produces are of superior beauty and brilliancy to those of the extracts, the reds it affords are inferior.

It seems that in the natural product there is a second coloring principle, namely, purpurine—to the presence of which the production of the fine orange reds is attributed. It has thus far been found impossible to reproduce the purpurine by artificial means; indeed, its

chemical constitution is yet but imperfectly known. The report concludes by expressing the opinion that the best tints will be produced by using the artificial alizarine and the madder extract combined—the latter being selected of a shade most nearly approaching orange.

The Preservation of Timber.—Before the French Academy, M. Boucherie, the son of the inventor of the system of injecting timber with sulphate of copper, recently declared that the tannate of protoxide iron does not possess the preservative properties attributed to it. He admits that it is a sure preventative against termites and worms, but he does not believe that it will preserve ligneous tissue, for, he declares, a minimum salt of iron, introduced into the vascular portion of wood, is rapidly converted into a maximum salt, a phenomenon accompanied invariably by the disorganization of the wood itself.

The author reported that he had experimented in dying balls black by injection of a solution of sulphate of protoxide of iron, of tannin and logwood, but he found that the wood was only preserved from decay when kept dry. The pyrolignite of iron, which possesses powerful antiseptic qualities, gave poor results. Balls, injected with sulphate of copper, were, on the contrary, perfectly preserved at the end of twenty-five years, and when analyzed, a notable quantity of the salt was found in them. He declared that it was an error to suppose that the sulphate of copper was very soluble, and that when exposed to the rain its preservative power disappeared after a certain time; the antiseptic agent, he declared, fixed itself in the elements of the wood, and could not be dissolved by washing; while cases of failure he attributed to a disease in the wood, the diseased tissue seeming to resist the sulphate.

An Oil Discovery of much importance is announced to have been made recently on the line of the Union Pacific railroad, about 800 miles west of Omaha, where the road crosses Green river. Here the approach of the road to the river is, for a considerable distance, through a cutting in rock, from 20 to 40 feet in depth. The discovery was accidentally made by the workmen engaged in the construction of the road, that the rock in question was oil-bearing. In heaping up fragments of the rock to protect the fire, it was observed that they ignited. Subsequent analysis and experiment, instituted at the instance of Mr. T. E. Sickles, the general superintendent of the road, resulted in establishing the fact that the rock was a shale quite rich

in mineral oils, yielding, by distillation, as much as 35 gallons of oil per ton of rock. The product which distills over is of two grades—one suitable for illumination and the other for lubrication. The deposits are said to extend over an area of more than 7,000 square miles, and it is predicted that they must form, in time, a possession of enormous value, inasmuch as the oil can be produced cheaply, and supplied to consumers on the Pacific coast, and those west of the Mississippi, cheaper than the oils of Pennsylvania or West Virginia can be transported to those localities. It is declared to be certain that these markets will very shortly be wholly supplied with oil from the newly discovered source, the proximity of the railroad affording ample transporting facilities for either the raw material or the manufactured product.

Exhibiting Photographs.—The *Scientific American* contains the following hint on the above subject, which may prove useful. The effect of photographic transparencies in the microscope, as well as on the screen, is greatly improved by placing a pale blue glass in the path of the illuminating beam. This artifice corrects the brown tone which they too often present, and gives depth and richness to the shadows.

Launch of the "City of Peking."—An event of much importance has recently transpired in the launch, at Chester, Pa., of one of the largest and most magnificent steamships ever constructed. The vessel in question, which is constructed throughout of American material, it is said, has but one superior in size, namely, the Great Eastern, and none in the quality of her materials or the elegance and perfection of her fittings. The ship was built for the Pacific Mail Steamship Line, and a second vessel, of similar construction and proportions, is now on the stocks for the same company. The "City of Peking" was built at the Delaware River Iron Ship Building and Engine Works, of which Mr. John Roach is President.

The dimensions and details of the vessel are as follows: length, 420 feet; beam 47 ft. 4 in.; tonnage, 6,000 tons; compound engines, 4,500 H. P.; propeller, 20 ft. 3 in. in diameter; four decks, and accommodations for two thousand passengers, fitted up in handsome style. The boilers are ten in number, and the estimated consumption of coal is placed at fifty or sixty tons per twenty-four hours. The steamship is entirely of iron, about five millions of pounds of metal having been used in the hull; the masts are four in number,

three of which are of iron, and used for ventilation, and she will be able to spread over 30,000 square feet of canvas. The speed of the vessel is stated at about 15½ knots per hour. The occasion of the launching of this magnificent specimen of American mechanical skill was one of festivity and rejoicing to the people of the ancient city of Chester, and attracted many prominent visitors from other cities to witness the ceremony. The launch was successfully accomplished, and attended with all the ceremonies usual on similar occasions.

The Austrian Athenæum is an institution destined to survive the Vienna Exposition, as well as to serve as a memorial of that event. It has been founded in the interest and for the instruction of mechanics and workingmen, and constructed after the model of the *Conservatoire des Arts et Metiers*, in Paris. Large numbers of articles left by exhibitors have been transported thither, together with a great number of models and other instructive apparatus, and a library of several thousand volumes.

The Accident at Cambria Iron Works.—The following particulars concerning the accident at the Cambria Iron Works, at Johnstown, Pa., a few weeks ago, are given by the *Engineering and Mining Journal*:—An unnoticed sprul stood on the floor of the pit, and a little water had made its way there, too. Unfortunately, the sprul stood just on the spot where the ladle with its charge of steel was lowered to bring it down to the ingot moulds. The ladle struck the sprul and rested on it, the rack in which the ladle rests continuing to descend. When this was noticed, the crane was brought up, under the ladle again, but the cogs on the rack, instead of interlocking with those on the ladle gudgeon, came up butt against them. Probably there was a slip which brought the ladle forcibly down to its seat again; but at all events there was a break on one side, and the ladle swung down, letting its contents into the pool of water on the pit floor. There was a tremendous explosion, and a shower of melted steel was thrown about, causing one of the worst accidents known in Bessemer practice in this country. In the early days of Bessemer work it was not such an uncommon thing to make a casting on the floor of the pit instead of in the moulds; but in such cases time was usually allowed the workmen to put themselves in safety. On one occasion, however, we believe at the Kœnigshütte, in Germany, the man at the valve allowed the converter to tip too far, and the melted iron began to run out on the floor. Then he became agitated, and,

instead of reversing the valves, turned them further, so that a heavy stream of melted iron poured out, and several men were injured. It is traditional that this accident caused the abandonment of the Bessemer process at the works named.

Franklin Institute.

HALL OF THE INSTITUTE, March 18th, 1874.

The meeting came to order at the usual hour, with Vice-President Henry G. Morris in the chair.

The minutes of the last meeting were read and approved.

The Actuary submitted the report of the Board of Managers, and reported that at their last meeting, held March 11th, 1874, the following donations to the Library had been read, viz.:

Annual Report on the State of the Finances to the Forty third Congress, first Session, December 1st, 1873. By Wm. A. Richardson. From the Hon. Secretary of the Treasury, Washington, D. C.

Annual Report of the Auditor-General of the State of Pennsylvania, etc., for the year 1872. From William A. Rolin, Esq., Philadelphia.

Reports of the Inspectors of Coal Mines of the Anthracite Region of Pennsylvania, for the years 1870 to 1872. From Wm. A. Rolin, Esq., Philadelphia.

The Giant Cities of Bashan and the Northern Border Land. From Eugene Nugent, Esq., Philadelphia.

The Coal Trade; a Compendium of Useful Information. From Frederick E. Saward, New York.

Quarterly Weather Report of the Meteorological Office, for October to December, 1872, and January to March, 1873. From the Meteorological Society, London.

Annual Report of the Chief of Ordnance to the Secretary of War, for the fiscal year ending June 30th, 1873. From the Chief of Ordnance U. S. Army, Washington, D. C.

Annales des Ponts et Chaussées for August, 1873. From the Editor, Paris.

Smithsonian Miscellaneous Collections, 255. The Constants of

Nature, Part 1. Compiled by F. W. Clarke, S. B. From the Smithsonian Institution, Washington, D. C.

Ordnance Memoranda, No. 14. Metallic Cartridges as Manufactured and Tested at the Frankford Arsenal, Philadelphia By Major T. J. Treadwell, Ord. Dept. From the author, Washington, D. C.

The Galvanometer and its Uses; a Manual for Electricians and Students. By C. J. Haskins, 1873. From D. Van Nostrand, New York.

Bulletin of the National Association of Wool Manufacturers, October—December, 1873. From the Association.

Astronomical and Meteorological Observations made during the year 1871 at the U. S. Naval Observatory. From Rear Admiral B. F. Sands, U. S. N., Washington, D. C.

Report on the Effects of the Sea Water and Exposure upon the Iron Pile Shafts of the Brandywine Shoal Lighthouse. By John D. Kurtz, Lt. Col. Engs., etc., and Micah R. Brown, Capt. of Engineers, Washington, D. C. From the authors.

Mr. William P. Tatham, from the Committee on Exhibitions, next presented a report of the steps taken by the Committee in the matter of holding an exhibition of Arts and Manufactures in the coming fall. After describing the premises, upon which it is proposed to hold the exhibition, particularly specifying the length and breadth of the building, and the amount of floor space which would be available for exhibition purposes, he read the following letter:

PENNSYLVANIA RAILROAD COMPANY,
PRESIDENT'S OFFICE, Philada., March 17th, 1874.

WILLIAM P. TATHAM, Esq., *Chairman of Committee on Exhibitions.*.

My Dear Sir:—I am directed by Mr. Thompson to say that the freight station at Thirteenth and Market streets will be at your disposal, for the use of the Franklin Institute as a place for holding an exhibition, on and after the first day of September next to the close of October; provided that we are not prevented from removal by circumstances now unforeseen.

Very respectfully,

STRICKLAND KNEASS,
Asst. to the President.

In consideration of the facilities placed at the disposal of the Institute by the letter just read, Mr. Tatham moved the following:

Resolved, That the Board of Managers are requested to hold an exhibition of American Arts and Manufactures the coming fall.

That the Board of Managers are requested to take measures to secure a guarantee fund to secure the Institute against loss; and

That the thanks of the Franklin Institute are due to the Pennsylvania Railroad Company for their prompt and liberal action, and that the President is requested to communicate this resolution to the President of the Company.

The resolutions were adopted.

Mr. Hector Orr moved a vote of thanks to the Committee for their prompt and efficient action in the matter submitted to them. Carried.

Mr. J. E. Mitchell expressed his satisfaction with the work of the Committee, and his estimation of the importance, both to the Institute and the city, of holding an exhibition as proposed.

Dr. Herricott, of Zanesville, Ohio, a visitor, expressed his gratification at the proposition of the Committee, and asked for information concerning the proposed conditions of admittance for those desiring to exhibit articles of manufacture.

Mr. E. Grey, of Chicago, Ill., then gave, by request, a statement of the space devoted to the late industrial exhibition in that city, and some details of its management and pecuniary success.

The Secretary then gave his monthly report on Novelties in Science and the Mechanic Arts, in the course of which Mr. Thomas Shaw described and illustrated, with the stereopticon, an improved relief block.—(*See Items and Novelties.*)

Mr. Hector Orr then announced the death of Mr. Thomas J. Weygant, a former officer of the Institute; and, after giving some detail of his life and his former activity and services as a member and officer of the Institute, moved the following resolutions:

Whereas, We have lost by death our late fellow-member and former manager of the Institute, Mr. THOMAS J. WEYGANT; therefore

Resolved, That the Institute hereby expresses sincere regret at the loss, and records its acknowledgment of the cheerful and faithful services of Mr. Weygant as a member and manager of the Franklin Institute.

Resolved, That a copy of these resolutions be addressed to the family of Mr. Weygant.

The resolutions were unanimously carried.

Mr. S. L. Wiegand then made a statement of the aid which he had received in illustrating his lectures before the Institute, through the kindness of Mr. Delamater, of New York, and moved, in consideration thereof, and the sending for use to the Institute, of one of the improved horizontal engines of the Rider pattern, manufactured by him, that the Secretary of the Institute be instructed to communicate

the thanks of the Institute to Mr. Delamater for his generous action in this matter. Carried.

The meeting was thereupon adjourned.

WILLIAM H. WAHL, *Secretary.*

NOTICE.

The attention of readers is called to the following extract from the minutes of the Board of Managers, held March 11th, 1874, which involves a change in the editorship of the Journal, to wit:

EXTRACT.

"Mr. B. H. Moore, Chairman of the Committee on Publication, presented the following letter:

HALL OF THE FRANKLIN INSTITUTE, Philada., March 9th, 1874.

'*Gentlemen of the Committee on Publication:*—

Having assumed other responsibilities, which make large demands upon my time, I fear that the attention which I will be able to bestow upon the Journal will be inadequate to its importance. I beg, therefore, to return the responsibility of its editorship into your hands, with the assurance that I will always look back to our harmonious relations with pleasure.

Very respectfully yours,

WILLIAM H. WAHL.'

"On motion of Mr. B. H. Moore, it was

"*Resolved*, That the resignation of Dr. William H. Wahl as editor of the Journal of the Franklin Institute be accepted, and that the thanks of the Board of Managers be tendered to him for his services in that capacity.'

"On motion of Mr. Moore, seconded by Mr. Helm, it was further

"*Resolved*, That the editorship of the Journal be tendered by the Committee on Publication to Prof. George F. Barker."

Civil and Mechanical Engineering.

REPORT OF THE COMMITTEE ON SCIENCE AND THE ARTS OF THE FRANKLIN INSTITUTE ON THE WESTINGHOUSE AIR-BRAKE.

HALL OF THE FRANKLIN INSTITUTE.

Philadelphia, Feb. 16th, 1874.

The Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania, for the promotion of the Mechanic Arts, to whom was referred for examination the Westinghouse Air-brake in its improved form, report, that they have been furnished by the inventor with every facility necessary for making a thorough examination and trial of this apparatus.

In its original and simplest form this brake consisted of a small steam engine placed on the locomotive, which, taking steam from the boiler, operated an air pump, which compressed air into a main reservoir secured beneath the cab. By a line of pipe extending back beneath the cars, and furnished between cars with a flexible hose, couplings and automatically acting valves, the compressed air was admitted at the pleasure of the engineer, who controlled its flow, by a three-way cock, to a series of brake cylinders, one under each car, the pistons of which were connected with and acted upon the ordinary brake levers and thus applied the brakes to the wheels. By reversing the three-way cock the air was allowed to escape from the cylinders and the brakes were off.

As quickness of action is of vital importance in the operation of a brake, and as it required an appreciable length of time, especially in long trains, for the air, even when under considerable pressure, to travel from the main reservoir to the brake cylinders to apply the brake, and also to pass back to the three-way cock to release them; the inventor made certain very important improvements, by means of which the compressed air can be admitted almost instantaneously into the brake cylinders, so as to apply the brakes without loss of time, and by the same means they can also be promptly released. The brakes can be so applied by the engineer, or by the conductor, or other person, from any part of the train. *Finally, these improvements secure this most remarkable and important result, viz: That the brakes*

will be instantly applied automatically in each car, (acting independently of all the others, and of train hands) *should* an axle break, or a car or the engine leave the track, or should the train be broken. The apparatus in this improved form is the one submitted to the Committee, and these improvements, in their general features, may be briefly described as follows:

An auxiliary reservoir for containing compressed air is placed on each car, close to the air cylinder. These auxiliary reservoirs are connected with the main reservoir by a pipe, without coupling valves, so that the same fluid pressure will be preserved in them as in the main reservoir. But the compressed air, before entering the auxiliary reservoirs, passes in each case through a valve box in which is a triple valve device, and from which valve box one port leads to the auxiliary reservoir, one to the brake cylinder, and a third to the open air. This triple valve is of such construction and arrangement with reference to the ports that, so long as the air pressure is kept up in the air pipe, the auxiliary reservoirs will be kept charged at the same pressure, and at the same time the ports intermediate between the brake cylinder and the external air will be open, and then, of course, the brakes will be off, and the train will be in running order. But on the air pressure in the air pipe being reduced, either by the engineer, who may open a cock for that purpose, or by the accidental rupture of the pipe, or by the accidental detaching of one or more cars, or by a trip device on each car, which, when a car jumps the track, shall automatically open a port in the air pipe; in any such or other like contingency the ports between the air-charging pipe and each auxiliary reservoir will be instantaneously and automatically closed, as also the ports between the brake cylinders and the external air; and also, at the same time, and by like instantaneous and automatic action, the ports will be opened between each auxiliary reservoir and its corresponding brake cylinder, so that the compressed air from the former shall flow directly into the latter, and operate without delay or loss of time, applying the brakes. By restoring the air pressure in the charging pipe, which is done by restoring connection with the main reservoir, the position of the triple valve is shifted so as to close communication between the auxiliary reservoirs and brake cylinders, and open communication from the latter to the external atmosphere. This operation is as quick in action as the other, and the brakes being thus released the train is again in running order.

The following full and accurate description, accompanied by draw-

ings and models, has been furnished by the inventor, in order to save the Committee the labor of preparing it. It gives a very full explanation of details of the apparatus.

The valve-box or case (fig. 3), is made in two or more parts, B, B^1, B^2. The air-charging pipe which leads back from the main reservoir, is attached to the port G^2, which latter then leads into the air chamber G. From the opposite chamber G^1 the port G^3 leads by a suitable pipe connection to the auxiliary reservoir, and a like pipe leads from the port H^1 to the brake cylinder. These devices are preferably arranged in such proximity to each other that the pipe connection will be short. The valve stem g has a limited motion longitudinally in the chambers G, G^1. At or near one end it carries the valve a, which seats on the annular V-shaped seat a^1 by suitable packing on its lower face, so as when seated, to close the port o^1. A series of wings arranged on this end of the stem g, act as guides in properly seating the valve a. A spring g^1, arranged on the other end of the stem g, bearing against the cap B of the valve case and against the back face of the valve seat b, holds the valve a to its seat when not raised therefrom by air pressure. The air chambers G, G^1 are separated by means of a flexible diaphragm n, preferably made by sheet metal, the outer edge of which is compressed between the adjacent faces of the two parts B, B^1, of the case annularly around the inner peripheries of the same, as shown in the drawings, with or without, but preferably with, interposed elastic packing rings or gaskets n^1, n^1, of india rubber or other suitable material, such as will ensure an air-tight joint around the outer edge of the diaphragm, and permit of a comparatively free motion of the diaphragm in peforming its function, and also prevent the wear which would be occasioned by the edge of the diaphragm working between metallic surfaces. From these annular compressing or packing surfaces, the parts B, B^1 of the case are so shaped inwardly as to give two annular and inwardly projecting flanges D, D^1, the distance between which gradually increases toward their inner edges, but the slope of each is such, that so much of the diaphragm n as comes between them, shall rest on one or the other at the end of each stroke of the stem g, or at the extremity of its motion in either direction. The sloping surfaces of these flanges D, D^1, constitute seats or rests to support the diaphragm after it has done its work, and thereby prevent its breaking. So much of the diaphragm as comes between these flanges may be corrugated annularly, if so desired, in which case such flanges should be a little

further apart, according to the depth of the corrugations—the object being to give the diaphragm a seat at the end of its motion in either direction. These flanges may extend inwardly any desired distance to, or short of, the compound nut or piston c, c^1. But it is not essential that the diaphragm should rest on the flanges over the entire surfaces of the latter, but merely on sufficient surface to prevent too great deflection by the fluid pressure employed, and consequent straining.

The diaphragm n has an eye at the centre through which passes the stem g, and the annular edge of this eye is clamped firmly, as shown in the drawings between two rings which form parts of the compound nut or piston c, c^1. The joint by which this clamping is effected, is preferably such that only the edge of the eye or hole of the diaphragm shall be gripped between such clamping rings—the adjacent surfaces of such clamping-rings being slightly beveled or flared away from the diaphragm, from the annular line of grip or clamp outwardly, as shown in the sectional view; and like packing can be employed here as at the outer edge of the diaphragm, if so desired, though probably it will seldom, if ever, be found necessary. The compound nut c, c^1, is free to move on the stem g, lengthways of the latter, and its face c^1 is provided with suitable packing so as to make a tight joint when seated against the annular ring of the valve seat b. Commencing at a point a short distance from the upper valve seat b, the stem g is turned smaller or reduced in size, as at e, and is also slotted as indicated at e^1. This reduction in the size of the stem g gives an annular air port e, by which communication is secured between the two chambers G, G^1. The compound nut c, c^1, which constitutes mechanically a piston, has an extension around the stem g, as shown at d, by means of which, in moving each way on the stem g, it alternately covers and uncovers the port e, and thereby closes and opens communication between the two chambers G, G^1. The annular port e communicates with the valve-chamber G^1 by means of ports e^2, which may be made in any desired number. Across the slot e^1 in the stem g, a cross-bar s is arranged, with its ends fixed in position in the adjacent walls of the nut c. From this slotted part e^1 a pin, s^1, extends along through and lengthwise of the stem g, till it buts against the stem s^3 of the third valve s^2.

The extension B^2 of the valve-box or case contains this valve s^2, made with a suitable guide s^4, which valve seats against a valve seat, so as to close an annular port u made therein. By means of this port,

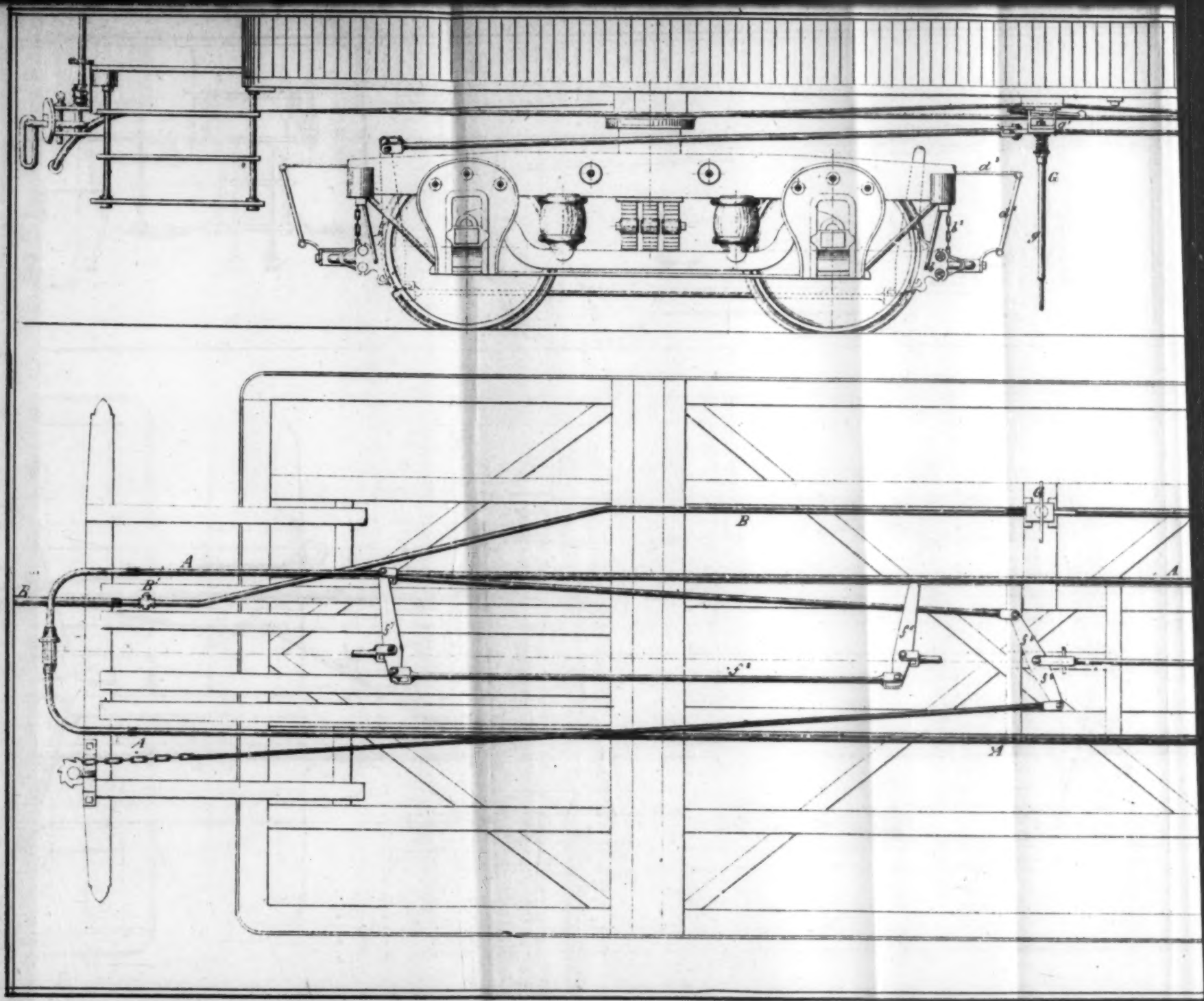
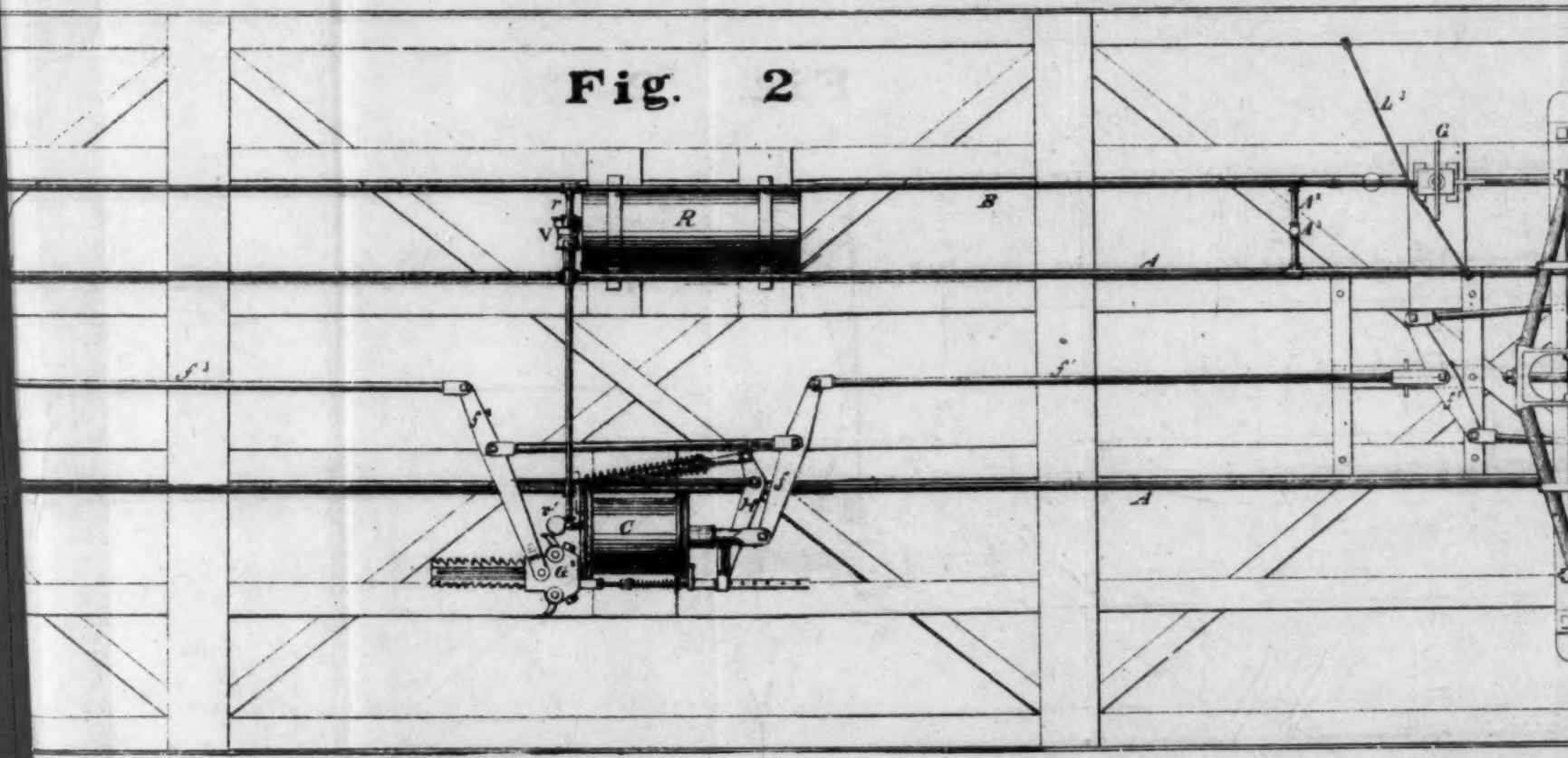

G
B
A
B'
A
B
A
A
A

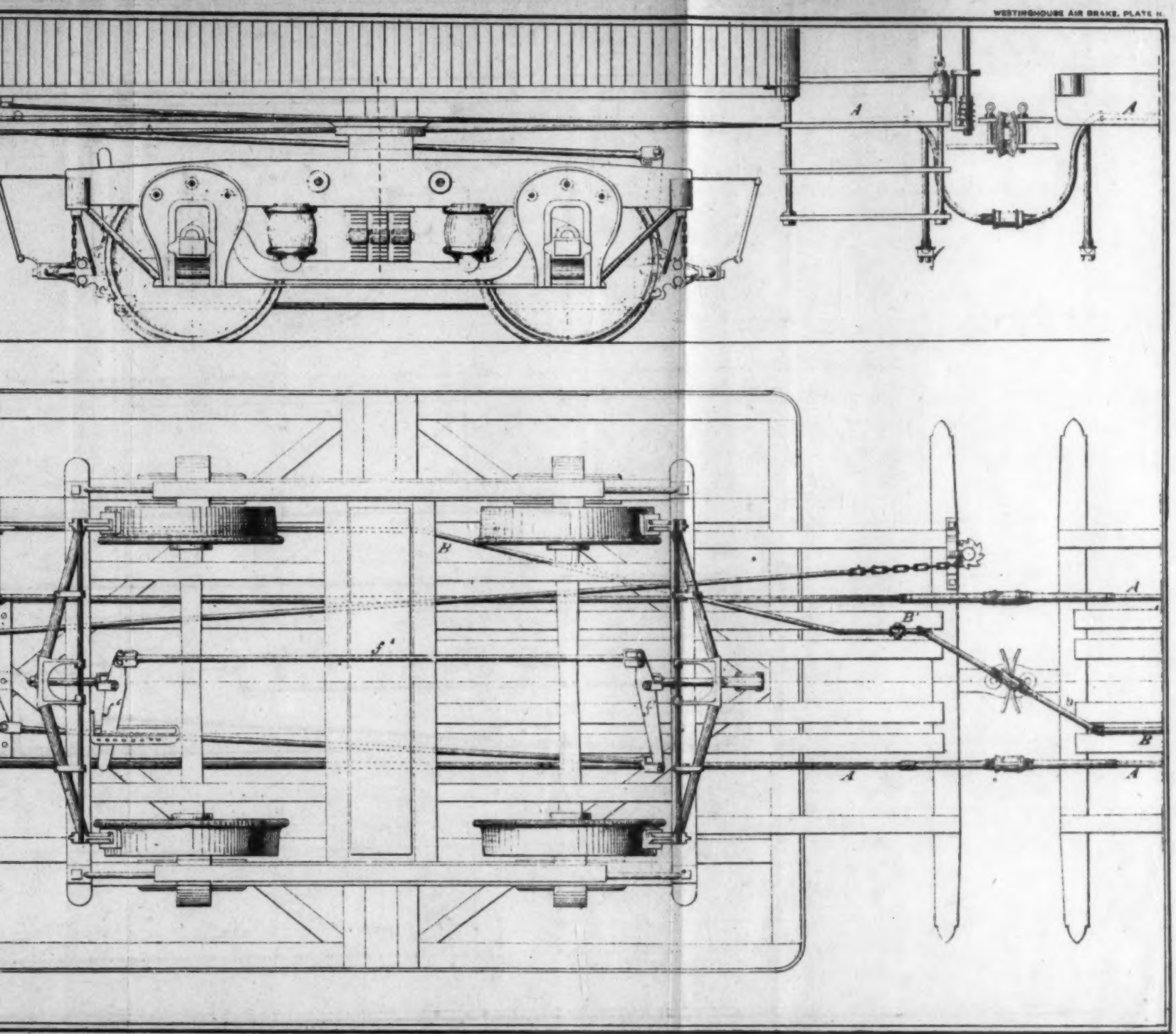
Fig. 1

WESTINGHOUSE AUTOMATIC SAFETY BRAKE

Manufactured by The Westinghouse Air Brake Co.
Pittsburgh, Pa.

Fig. 2





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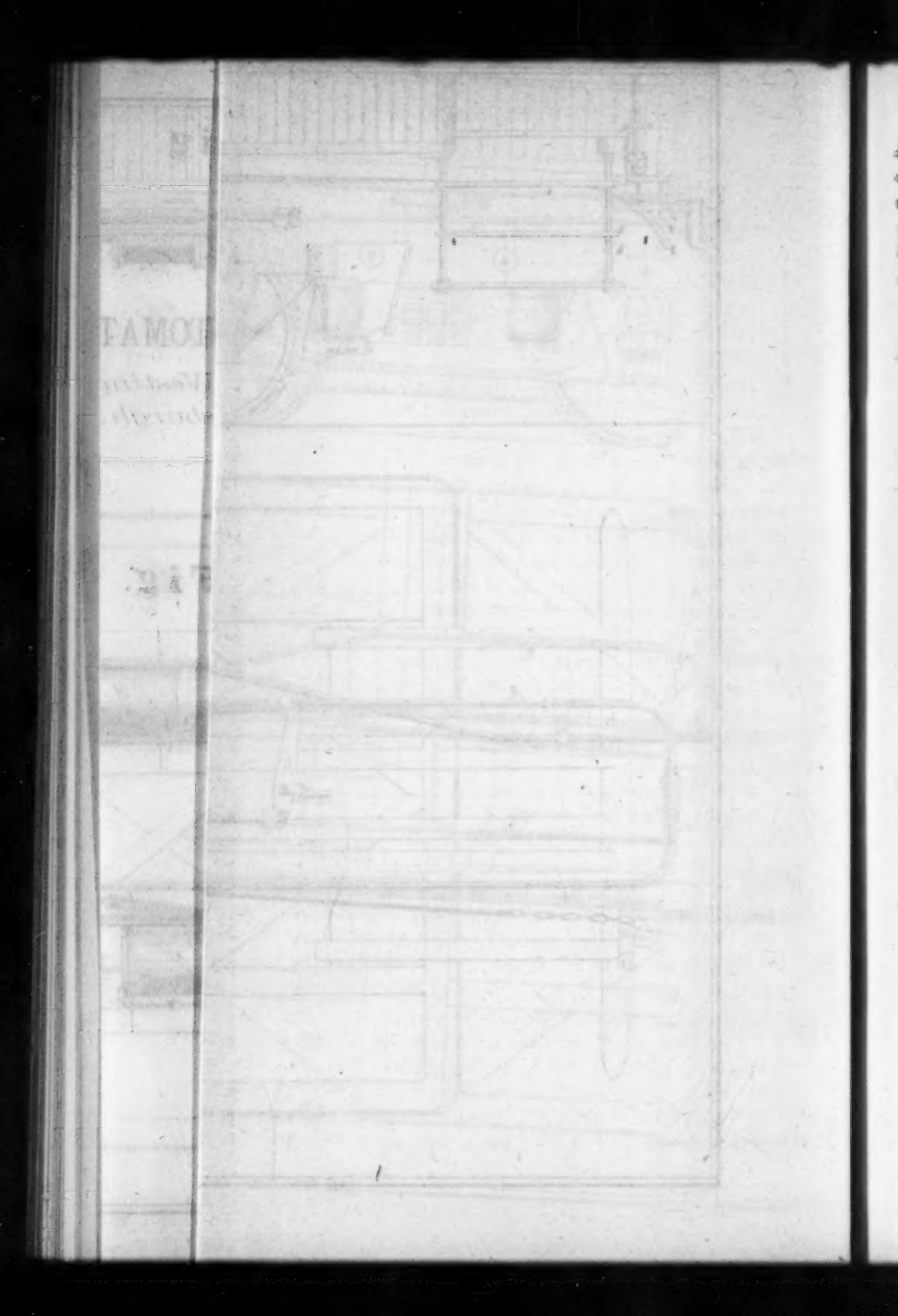

and the passages u^1, u^2, communication is effected (the valve s^2 being unseated) between the brake cylinder by the port H^1, and the external atmosphere by the ports h^2, for the purpose of allowing the compressed air to escape from the brake cylinder when the brakes are to be released or let off. The valve s^2 is seated and unseated by the action of the spring h, and the pin s^1 acting on the stem s^3, as presently to be explained. To provide for an equilibrium of air pressure on both sides of the valve s^2, the holes r are bored through it and its stem as shown.

The operation of the device described is as follows:

If air or other gas or fluid under pressure, be admitted by the port G^2, it will, by the pressure it exerts on the flexible diaphragm n, cause the piston c, c^1, with its diaphragm n, to be shifted on the stem g until it occupies about the position shown. The cross-bar s will then have opened the valve s^2, and the valve a will be closed by means of the spring g^1, or by fluid pressure or both; also, the annular port e will be opened. In such case, the air or other fluid will pass, as indicated by the arrows, from the chamber G, along the ports e, e^2, into the chamber G^1, and out of the port G^3 to the auxiliary reservoir, whereby the auxiliary reservoir will be charged with compressed air of such density as it may be desired to store up for the purpose of operating the brakes. At the same time, by means already described, the valve s^2 is unseated, and thus a direct communication is opened from the brake cylinder, through the port H^1, and ports h^2, with the external atmosphere. The brakes are then off. As soon as the pressure on the opposite sides of the diaphragm n and compound nut c, c^1, is equal or nearly so, the spring h in the lower part of the case, acting against the valve s^2 and through the stem s^3, pin s^1, and cross-bar s, will cause the piston $c\ c^1$ to slide upward on the stem g, and thereby cut off communication through the annular passage e, and will seat the valve s^2 so as to cut off the escape of air from the brake cylinder through the escape ports h^2. Then, if the pressure exerted in the chamber G on the diaphragm n be reduced by allowing a portion of the air to escape from the charging-pipe, the pressure of the air or other gas, acting back through the port G^3 on the opposite side of the diaphragm n, will raise the piston $c\ c^1$ against the valve seat b, compress the spring g^1, and by moving the stem g in the same direction, will lift the valve a from its seat a^1, and thereby open communication from the chamber G^1, through the port o^1, with the port H^1. The compressed air or other gas or fluid will then be free to pass

from the auxiliary reservoir, through the ports G^3, o^1, and H^1, to the brake cylinder, so as to charge the same and apply the brakes in the usual way. The area of the opening through the port o^1 is regulated by the distance which the plug o is caused to move outwardly from the port. Hence, if the pressure be reduced but slightly at G^2, the plug o will be raised but a short distance, and a small amount of compressed air or other fluid will be allowed to pass through and out at the port H^1. When the equilibrium is thereby restored in the chambers G, G^1, the valve a will resume its seat and close communication. If the pressure in the chamber G be materially increased, the valve a^2 will be unseated, as already described, and an open communication be made from the brake cylinder through the port H^1 and h^2, to the external atmosphere. By the use of the taper plug o, in the manner described, and by regulating, as can easily be done by the use of suitable cocks, the amount of pressure in the chambers G, G^1, it is easy to regulate the amount or density of the air which is permitted to flow through the ports o^1 into the brake cylinder, and consequently easy to regulate and adjust, at all times, the force with which the brakes are applied, and such force may be varied from the maximum power of the brakes down to the fractional part of a pound, in excess of ordinary atmospheric pressure.

In the use of the apparatus such as that to which this improvement appertains, when a car is detached from a train, the charging pipe should be closed at each end before the car is detached, to prevent the brakes being applied or "set" by the reduction of the pressure. In such case, if, as will sometimes happen, the air leaks slightly from the charging pipe, the valve a will be raised slightly from its seat, and the air pressure will pass slowly from the reservoir by the port G^3, through the port o^1, and by the port H^1 to the brake-cylinder, and thereby set the brakes. To prevent this result, a relief-valve is arranged on the pipe H, which latter leads from the port H^1 to the brake-cylinder. This valve consists of a cylindrical box R, having a cap R^1 with a small port r^1 bored therein, and faced with a rubber or other suitable packing r^2. At its opposite end it communicates with the bore of the pipe H by a small port r^3. In the chamber of the case R is a valve R^2 working loosely therein, and having on its upper end a seat of suitable form, so that when forced up by the ordinary pressure in working the brakes, it will seat against the packing r^2 and effectually close the port r^1. But when the pressure in the pipe H is only such as may result from leakage, as above mentioned,

such pressure will pass out through the port r^3, and, escaping through small grooves r^4, or tilting the valve R^2 off its lower seat, will pass up around it without seating it upward. The amount of pressure which may in this manner be allowed to escape without the application of the brakes, may be varied at pleasure by varying the size and weight of the valve R^2.

For greater convenience and facility in opening and closing the valve case B, B^1, a fastening device has also been devised, as shown in the drawings. The part B fits on to the part B^1 like a cap, and is held in place by means of eye-bolts m, which fit into a recess, or between lugs, as shown. These eye-bolts are held in place at one end by means of pins m^1, which pass through the eye-ends of the bolts and through lugs m^2 on the one part B^1 of the case, and said bolts are threaded at the opposite ends, and secured so as to hold the two parts of the valve case together by means of screw-nuts m^3. The threaded ends of the bolts project a short distance beyond the outer faces of the nuts, when the latter are screwed down tight, and such projecting ends are rivetted or upset slightly, so that while leaving room for the nuts m^3 to be unscrewed sufficiently for the bolts m to swing outwardly from the recesses in the cap B—turning for that purpose like hinges on the pins m^1—they cannot be screwed off entirely so as to be lost, but will always be in place for use. Thus a convenient and speedy mode is provided of opening the valve-case B, B^1, for cleaning, repairing, adjusting or replacing any of the devices included therein, without disconnecting or straining the pipes.

In the apparatus described, each auxiliary reservoir has about four times the capacity of the corresponding brake-cylinder. The charging pipe, which is made of three-quarter inch gas pipe, extends from the main reservoir back under the whole train, and is provided with a three-way cock on the engine, by which the entire apparatus for ordinary braking purposes is placed under the control of the engineer. This pipe is, between the cars, provided with flexible sections, on the outer side of which are couplings, which are counterparts or duplicates of each other. These couplings have no valves for retaining, when uncoupled, the compressed air; but a cock is inserted in the pipe, at or near each end of each car, for closing the pipe at the rear end of the train, and also at each end of a car, when such car is detached from a train.

The advantage of an instantaneous application of the brakes at the will of the engineer is obvious. In the system heretofore in use, the

pressure has to be transmitted back through the train. In the improvement just described, the requisite pressure is kept up throughout the train, ready to be put into operation. In the former case, 1,200 cubic inches of compressed air at 35 lbs. pressure per square inch for each car, or 2,800 cubic inches at atmospheric pressure, have to be transmitted back from car to car to apply the brakes effectually. In the latter case, a reduction of 15 lbs. in the pressure of the air in the pipe (which is equivalent to the pressure of *one* atmosphere) is all that is necessary to effect the same result. This reduction of pressure is equivalent to the transmittal of 360 cubic inches of air for each car at atmospheric pressure. The saving of time in applying the brakes will then be approximately in the proportion of the quantity of air transmitted, or as 2,800 is to 360.

This relative proportion is affected only by the friction of the air in passing through the pipes, and this element is comparatively inappreciable as affecting the result. By arranging the auxiliary reservoir and the brake-cylinder of each car in close proximity with each other, the time required for the air to pass from the former to the latter will be so small as to be unimportant; and as a train, moving at the rate of forty miles per hour, passes over fifty-eight and two-thirds feet per second, or a little more than the length of an ordinary passenger car, it will be obvious that, in case of danger, every second of time saved in the application of the brakes immeasurably reduces the chances of disaster, and multiplies, in a geometrical ratio, the probabilities of safety to both travelers and train.

From the construction of the apparatus, it will be obvious that its durability is limited only by the number of times that the valves described will bear the required operation in the application and release of the brakes. All the material being of metal, will not be appreciably affected by age.

To test thoroughly the number of operations that would be required to destroy the apparatus or any breakable part of the same, this triple-valve device was arranged in connection with a charging pipe and brake-cylinders as in a train, while a three-way cock on the pipe was operated by machinery in like manner as in ordinary use for braking purposes. After the reservoirs were charged with compressed air at ordinary working pressure, the machinery which opened and closed the three-way cock was set in motion, and the triple-valve began its work. *After* 309,000 *strokes* in opening and closing the ports, which was equivalent to applying and releasing the brakes that number of

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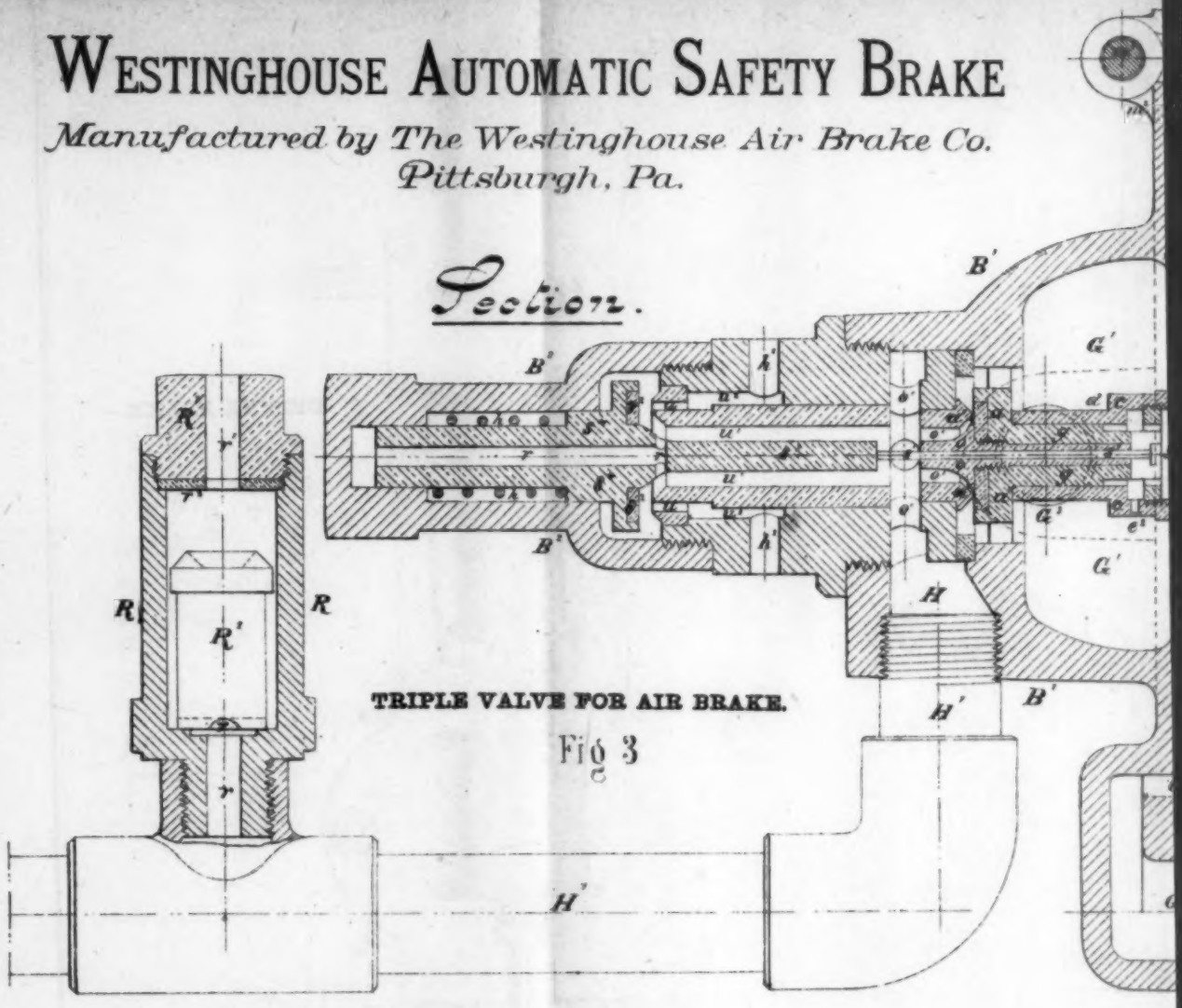
Section.



TRIPLE VALVE FOR AIR BRAKE.

Fig 3

BRAKE BEAM.

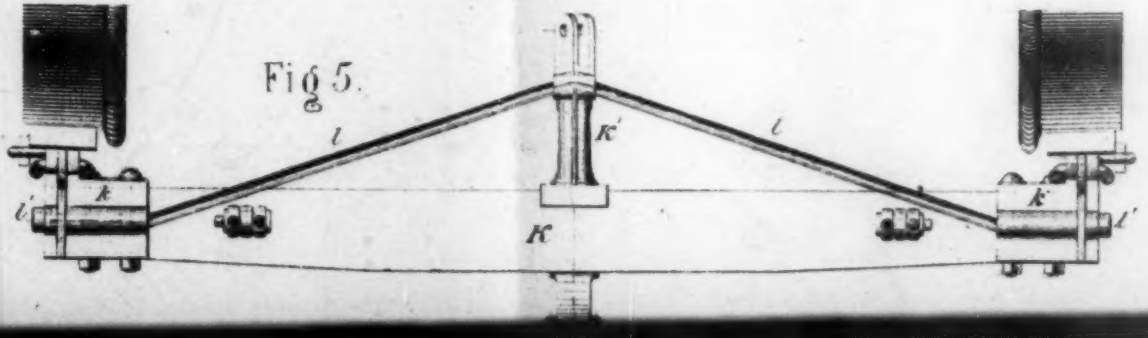


Fig 5.

SAFETY BRAKE

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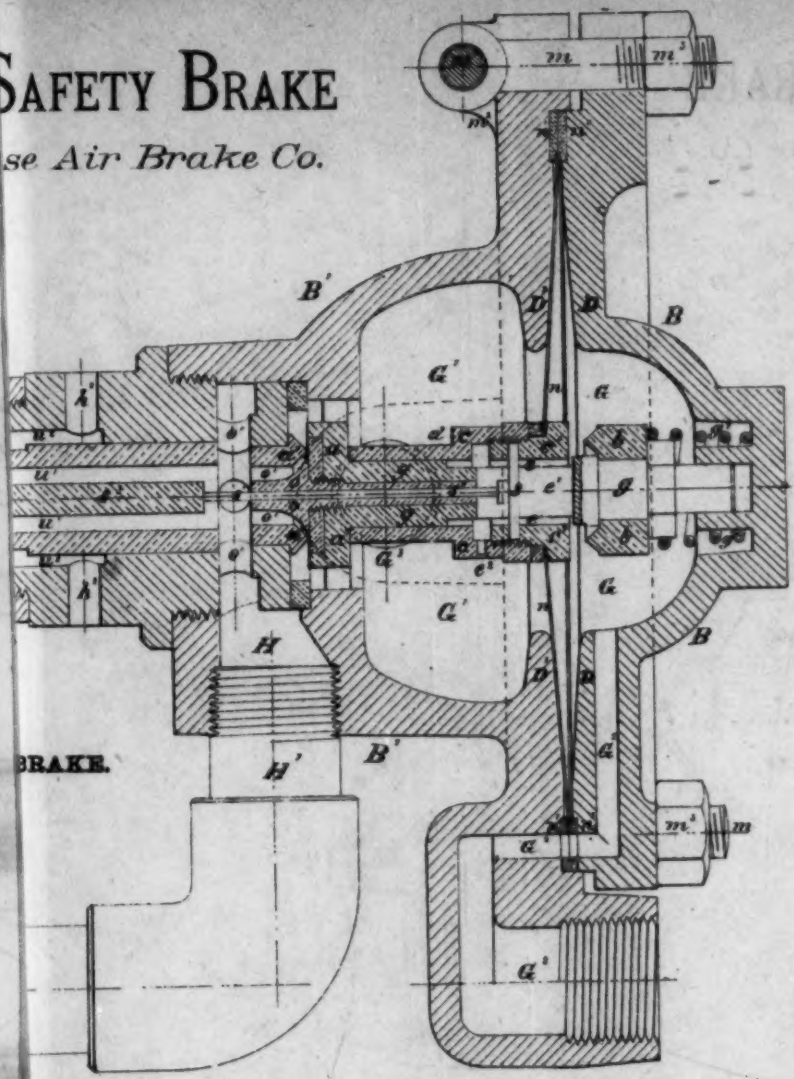
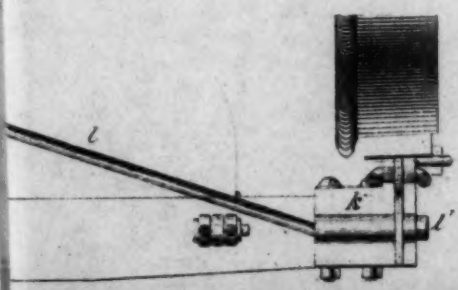
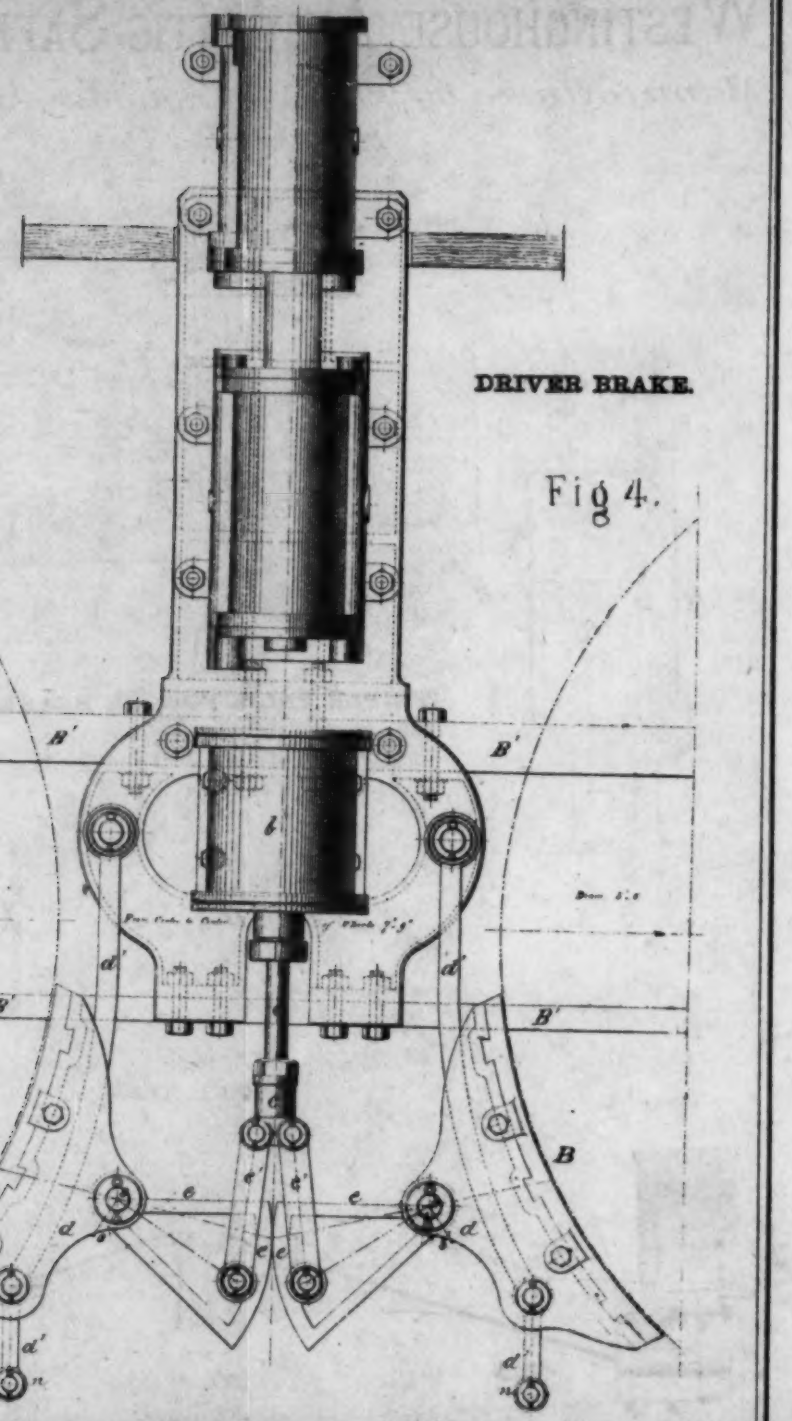






DRIVER BRAKE.

Fig 4.

times, it was still found in perfect working order, so far as it could be ascertained from its operation. Upon examination it was found that the diaphragm n showed signs of cracking at a point between the rubber packing rings n^1, n^1. The other parts of the triple-valve made 460,000 strokes without any indication of failure. These experiments have been continued at great length, and in no case has the triple-valve failed to perform its work promptly and effectively. In these tests, the pistons of the brake-cylinder receive a full and complete stroke, so that the shock, and, of course, the strain on the triple-valve, is more severe than in ordinary train use.

The triple valve above described is inserted at V, Fig. 2, in which figure B is the charging pipe, R the auxiliary reservoir, and C the brake cylinder. Figs. 1 and 2 also show at A, A the brake pipes of the old Westinghouse Apparatus as heretofore in general use. In these figures they are, for convenience of illustration, shown as combined with the automatic system on the same car; and when combined in this way either system of apparatus may be used at pleasure by the interposition of a double ended check valve at v^1. At G, Figs. 1 and 2, a trip valve and tripping arm is placed so as to apply the brakes automatically in case of the derailment of a car Also, by a conductor's cord attached to a lever L^3, means are provided to enable the conductor to apply the brakes at his pleasure from any car on the train. The arrangement of the brake rods and levers will be readily understood from the drawings without further description.

Another valuable improvement which has been made in the Westinghouse system of apparatus relates to brakes for the driver wheels of locomotives. This feature of the system is illustrated in figure 4, in which the ordinary drive wheels are shown at B, B, and B^1 indicates portions of the frame work of the locomotive. The brakes proper, d, are recessed on their rear faces and are pivoted to the hangers, d^1, below and a little forward of their centres of gravity, so as naturally and by their own weight to swing clear of the wheels. To these brake-shoes, blocks or holders, d, are pivoted the eccentric-faced segment levers, e, e, in such position that their circular or curved faces or peripheries shall work against each other or against a block or other desired device placed between them. At any desired points in the direction of the length of their curved peripheries, and preferably near the lower ends of the same, the connecting rods, or stirrups, c^1, are pivoted, which latter at their upper ends are jointed to the lower end of the piston stem, c. The segment levers,

e, are somewhat eccentric, their working faces at the lower ends being somewhat further from their centres of motion than such faces are at their upper ends. In the drawings, *s* indicates the centre of motion in each, and s^1 the centre of curvature. The amount of this eccentricity may be varied at pleasure.

This apparatus, together with the brake cylinder, *b*, is duplicated on the opposite side of the locomotive. The compressed air is admitted by a pipe from the main reservoir, with an interposed three-way cock, beneath the piston in the brake cylinders *b*, and by the upward thrust imparted thereby to the piston stem *c*, shifts the segment levers *e*, so as, acting on the principle of the toggle joint, to apply the brakes effectually to the wheels. By this construction, in fact, the ordinary advantages of the toggle joint are secured along with a uniform, or nearly uniform, application of the power at all points of the stroke, until the brake shoes are worn entirely away. Where the distance between the drivers, *B*, *B*, is too small to admit of the introduction and use of both the segment levers, *e*, *e*, one only may be used, pivoted to one of the brake blocks, and with its eccentric face working against a friction roller pivoted to the other brake block at *s*.

It may safely be said that the time is not far distant when the wonder will be that driver brakes could ever have been dispensed with. In an ordinary passenger train, of say a locomotive, tender and six cars, the aggregate weight of the cars may be stated in round numbers at ninety tons, and that of the locomotive and tender at say forty-five tons, or, in other words, about one-third the weight of passenger rolling stock has been used without any brake power whatever. Thirty-three per centum of the braking power applied to the cars is expended in stopping the locomotive and tender, with a consequent enormous and undue strain on the couplings, which, of course, is greatest between the engine and tender and decreases backwards toward the rear of the train. This strain, of course, tends to pull the train apart and leave the locomotive free of control except by reversal of the engine. Also if, as heretofore, the car brakes are applied with sufficient power not only to arrest the motion of the cars, but also with fifty per centum more power in order to stop the locomotive, it is obvious that the car brakes, wheels and trucks, must be made enough heavier and stronger than would otherwise be required, in order to enable them to resist this fifty per cent. of additional strain. Or, if they are still made as strong in this respect as heretofore, the use of driver brakes would enable the engineer to stop his

train so much the quicker; and this efficiency of the driver brakes is further augmented from the fact that the adhesive power of the steel tires of the drivers on the rails is so great, as compared with that of cast iron wheels, that a greatly increased braking power may be applied to the drivers without sliding them; also, as a further consideration, the locomotive is the first to run into danger, it occupies the position where danger is greatest, and, except in great catastrophes, the chief loss to the company is occasioned by injury to or destruction of the locomotive. And these elements of danger are augmented when a train breaks in two, since then the aggregate braking power of the train is diminished in proportion to the number of cars detached. It would seem that, in a perfect system of braking apparatus, the braking power applied should be distributed, as near as may be, on locomotive, tender and cars in proportion to the weight of each. This improvement is intended to be a step in this direction.

The construction of our locomotives is such that the ordinary brake beam cannot be employed, nor can the power to operate it effectively be got to it without great expense. The distance between the drivers is usually small—too small for any but the simplest apparatus, and to meet the requirements such apparatus must act quickly, surely and with great power. If operated from above, allowance must be made for the vertical motion of the engine on its springs. This motion, though small, is so great as to render inapplicable for applying the power any device which has only a fixed length of motion, or which, after completing its motion, has no "give" or elasticity. An inspection of the drawings will show that all these requirements are fully met in the Westinghouse improvement, and especially as to the last one named, the elasticity of the compressed air in the brake cylinder takes up any inequalities which may arise from the motion of the engine on its springs or other like causes.

Fig. 5 shows the construction of a new brake beam, which Mr. Westinghouse is now introducing in connection with his brake. It consists of the usual wooden bar K, on the ends of which are attached cast metal boxes *k*. The tension rod *l* has upset heads l^1, which bear against the outer ends of the boxes. The strain in braking is then, by the post K^1, divided between the bar K and the tension rod *l*. The shoe-holders are cast with the boxes, and the shoes are made removable and reversible. By means of a spring L in connection with the links, by which the brake beam is hung, provision is made by which the brake shoes, while moving from the wheels, will

at each end move a uniform distance, or, in other words, when the brakes are off, the shoes will swing wholly clear of the wheels throughout the entire length of their working faces.

Experiments.

A train fitted with the improved apparatus, and consisting of an engine, tender and seven passenger cars, was brought from Pittsburg, and placed at the disposition of the Committee on the 20th of May last. It was understood that the air-brake apparatus was not made for this especial occasion, but was like those of the same kind in ordinary use upon the Pennsylvania Railroad.

This train was taken in the afternoon of the day mentioned to a part of the road suitable for the purpose, about fifteen miles from the city, and the experiments about to be described were made under the direction of the Committee and in the presence of a number of other persons interested in railroad matters, who had been invited to witness the trials. There were perhaps fifty or sixty persons in all, and they constituted the living load of the train.

The speed of the train in all the experiments was estimated, by noting the time in passing mile posts, with a considerable degree of accuracy, by members of the committee. It is believed the speed is rather under than over estimated.

The distance run after applying brakes on giving signals, was ascertained by measurement with a tape-line from a stick with a small red flag upon it, which was thrown from the train at the moment of giving the signal or applying the brakes. A correction has been made for the space passed over by the train while the flag was falling to the ground.

The time consumed in bringing the train to rest was accurately ascertained by means of a stop-watch, which indicated to the fifth of a second.

For the "grades," the Committee are indebted to the courtesy of Mr. W. H. Wilson, Chief Engineer of the Pennsylvania Railroad.

First Experiment.—Stop to be made by the engineer in answer to a signal given by the conductor with the bell-rope. Distance to be measured from a flag thrown from the engine simultaneously with the application of the brakes.

Result.—The train came to a full stop in sixteen (16) seconds, having run a distance of 503 feet from the flag. The speed was thirty miles an hour, *up* a grade of 29·6 feet per mile. The time

required for the flag to reach the ground after being thrown out was about seven-tenths of a second, and adding the distance passed over by the train in this time, say 44 feet, we have 547 feet as the distance passed over by the train after the brakes were applied, and being only a little more than the length of the train.

Second Experiment.—Stop to be made by applying the brake from the interior of one of the cars. Time and distance ascertained as before.

Result.—The train came to a full stop in fifteen (15) seconds, having having run a distance of 506 feet. The speed was between 30 and 35 miles per hour, *down* a grade of 31·7 feet per mile. Assuming the speed to have been 32 miles per hour, there should be added for distance run, during the falling of the flag, 47 feet, making the actual distance run by the train after application of the brakes 553 feet.

Third Experiment.—Stop to be made by severing the train. *Brakes working automatically;* flag to be thrown out at the instant of parting.

Result.—In this case the train was running at a speed of *full* thirty miles per hour, down a grade of 26 feet per mile, when five rear cars were detached. These cars came to a full stop in 11·8 seconds from the time the train was cut, having run a distance of 367 feet, or, with the allowance for falling of the flag, 411 feet. The forward part of the train came to rest a very short distance in advance.

Fourth Experiment.—Similar to the last, except that the engine alone was severed from the train. Brakes acting automatically, as in the last experiment. The speed was forty miles an hour down a grade of 28·2 feet per mile. The train came to a rest in 10½ seconds, having run by the flag 265 feet, or, with allowance for time of falling, 323 feet.

This experiment was then repeated, the Committee and others having left the cars to witness it while standing along side the track. The train came to rest in 10½ seconds, running 291 feet from the spot where the brakes were applied. The speed was very great, and was judged to be forty-five miles per hour. The stop at this unusual speed was made in about the length of six cars.

Fifth Experiment.—Stop to be made from one of the cars. The engine to remain wide open, working ahead.

Result.—The train came to a full stop in 15·8 seconds, having run from the flag 502 feet, or, with allowance as before, 555 feet. The speed was thirty-six (36) miles per hour, up a grade of 29·6 feet per mile.

Sixth Experiment.—To show how quickly the train could be got in motion again after stopping, two stops were made in succession, and the interval of rest in each case was timed by the Committee. After the first stop, the train was in motion again in 4½ seconds, and after the second stop in 2·8 seconds.

It was stated that the engineer did not fully understand his instructions when making his first stop, and the difference in time is thus accounted for. The rails were slightly wet.

Seventh Experiment—was scarcely necessary, as it was simply to show that the triggers which open the valves and apply the brakes when the cars leave the track would act when they meet an obstruction. This was so obvious as not to require demonstration.

This completes the record of the experiments made by the Committee. They were all entirely satisfactory, and they demonstrate very clearly the extraordinary efficiency of this brake apparatus.

The first experiment shows that a train, moving down a grade of about 30 feet per mile, at a speed of 30 miles per hour, may be stopped by the engineer in about a quarter of a minute of time, and in a distance of less than 550 feet.

The second experiment shows that a train may be stopped (by simply pulling a cord in any part of it), when going down a grade of about 32 feet per mile, at a speed of about 32 miles per hour, *in a quarter of a minute of time*, and in a distance of 550 feet, or less than its own length.

The third experiment is more remarkable. It shows that if the cars become detached, or the train be broken in any way, the brakes are instantly applied automatically. The train, and each car in the train, as it were, takes care of itself, and nothing depends upon the promptness, or presence of mind, or judgment of the train hands.

It is obvious that in this way, the brakes are applied more promptly than would be possible by the train hands, and under circumstances where instant action is extremely important. The same action would take place if an axle or wheel were to break, or if the cars or any one of them should leave the track.

The fourth experiment was similar to the last, and gave similar results.

The fifth experiment shows the extraordinary efficiency of this break to control the train. With the engine working ahead, with the throttle wide open, and at a speed of about 36 miles per hour, up a grade of 30 feet per mile, the train was stopped in about a quarter of a minute, and in a distance of 555 feet.

In all these experiments, the cars were brought to rest quietly, without shock, or any action which would disturb passengers, or throw them from their seats.

The Committee have given consideration to the question of the probable durability of this apparatus, and to its liability to derangement. Considering what this brake accomplishes, and reminding that there is a complete self-acting brake in each car, this apparatus may be considered as simple, and they can see no reason why it should get out of order, or be unreliable if it is cared for with reasonable attention. It is of course more complicated than the common hand brake, but it is vastly more effectual and greatly diminishes the risk of injury to passengers and rolling stock.

A few figures will show the importance of the prompt action of the brake. If a train be running at the rate of 35 miles per hour, (a very common speed,) it passes over 3,080 feet per minute, or, about the length of an ordinary car, in one second. If two trains approaching each other at that speed should come into collision, it would require only half a second to "telescope" one car into another its full length. A half second of time might therefore jeopardize the lives of fifty or sixty passengers.

In conclusion, the Committee say that these experiments have demonstrated to them the extraordinary efficiency of this apparatus, and they especially call attention to the value and importance of the arrangement which secures the instant automatic application of the brakes on the engine and on each car of the train, independently of the train hand, in certain contingencies, which are of common occurrence and are the cause of frequently disastrous accidents.

The Committee believe that by contriving and introducing this apparatus, Mr. Westinghouse has become a great public benefactor, and deserves the gratitude of the traveling public at least. They believe that his inventions are worthy of, and should receive the award of the Scott's Legacy medal, and they therefore conclude this report by proposing the adoption of the following resolutions:

Resolved, That the report of the Sub-Committee, appointed to examine and report upon the Westinghouse Air Brake, be accepted and be referred to the Committee on Publication, to print in the *Journal of the Franklin Institute* such part thereof as they may deem proper or necessary to make known to the public the result of this examination.

Resolved, That this Committee (of Science and Arts) recommend to

the Board of Managers of the Institute, that they make the award of John Scott's Legacy Premium and Medal to George Westinghouse, Jr., of Pittsburgh, Pa., for his improvements in Air Brakes for railway trains.

All of which is most respectfully submitted.

JOHN H. TOWNE,
S. W. ROBERTS,
J. S. BANCROFT,
CHARLES M. CRESSON, M. D. } *Committee.*

By order of the Committee,

D. S. HOLMAN, *Actuary.*

[Entered according to the act of Congress, in the year 1873, by John Richards, in the office of the Librarian of Congress at Washington.]

THE PRINCIPLES OF SHOP MANIPULATION FOR ENGINEERING APPRENTICES.

BY J. RICHARDS, Mechanical Engineer.

(Continued from page 174.)

MACHINERY FOR TRANSPORTATION AND FOR MOVING AND HANDLING MATERIAL.

Steam machinery, as applied to the transport of material and travel, in navigation and by railways, comprises a large share of all that is constructed; and when we consider that this vast interest of steam transport is less than a century old, and estimate its present and possible future influence on human affairs, we begin to realize the relation that mechanical science bears to modern civilization.

To follow out the application of power to the propulsion of vessels and trains, with the many abstruse conditions that would, of necessity, be involved, would be to carry this work far beyond the limits within which it is most likely to be useful to the apprentice; besides, it would be going beyond what can properly be termed shop manipulation.

Marine and railway engineering have engrossed the best talent in the world, investigation and research have been expended upon these subjects in a degree commensurate with their importance, and it would be hard to suggest a single want in the many able text-books that have been prepared upon the subjects.

Marine and railway engineering are sciences that may, in a sense,

be separated from the ordinary constructive arts, and studied at the end of, a course in general mechanical engineering, but are hardly proper subjects for an apprentice to take up at the beginning of a course.

In treating of machinery for transport, as a class, the subject, as far as treated here, will be confined to moving and handling material as one of the processes of manufacturing, especially in connection with machine construction.

If the amount of time, expense, labor and machinery devoted to handling material in machine shops is estimated, it becomes a matter of astonishment to as many as have not previously investigated the matter; as an item of expense the handling often exceeds the fitting on large pieces, and in the heavier class of work demands the most careful attention to secure economical manipulation.

It will be well for an apprentice to begin at once, as soon as he commences his course, to note this matter of handling material, watching the operation of cranes, hoists, trucks, tackle, rollers; in short, everything that has to do with moving and handling.

The machinery and appliances in ordinary use are simple enough in a mechanical sense, but the principles of handling material are by no means as plain or easy to understand.

The diversity of practice seen in the various plans of handling and lifting weights fully attests this last proposition, and it is questionable whether there is any other branch of mechanical engineering that is treated in a less scientific way than machinery of this class; I do not allude to the mechanism of cranes and other devices which are usually well proportioned and generally well arranged, but to the adaptation of such machinery with reference to special or local conditions.

There are certain inherent difficulties that have to be encountered in the construction and operation of machinery for lifting and handling that are peculiar to it as a class; among these difficulties is the transmission of power to movable mechanism, the intermittent and irregular application of power, severe strains, also the liability to accidents and breakage from such machinery being controlled by the judgment of an operator.

Ordinary machinery, on the reverse, is stationary, consumes a regular amount of power, is not subjected to such uncertain strains, and as a rule acts without its operation being controlled by the will of attendants.

The functions required in machinery for handling material in a machine shop corresponds very nearly to those of the human hands. Nature has exceeded man in the adaptation of lifting and handling mechanism; in fact, we cannot conceive of anything more perfect than the human hands for handling material—a duty that forms a great share of all that we term labor.

As machinery for handling material, the hands may be considered as capable of exerting force in any direction, vertically, horizontally or at any angle, moving at various rates of speed, as the conditions may require, and with varying force within the limits of human strength. These functions enable us to pick up or lay down a weight slowly or carefully, but to transport it at a rapid rate to save time, to move it in any direction, and without the least waste of power, unless it be in ascending with a load when the body has to be carried up and down at the same time. The travelling swing cranes that are sometimes used in machine fitting establishments are the nearest approach that has been made to the human frame in the way of handling machanism; they, however, lack that very important feature of a movement the speed of which graduated at will.

In handling a weight with the hands it is carefully raised, and laid down with care, but moved as rapidly as possible throughout the intervening distance.

It is evident that machinery of any kind for handling and lifting, that moves at a uniform rate of speed, and this rate of speed adapted, as it must be, to the conditions of starting or depositing a load, much time must be lost in the transit, especially when the load is moved for a considerable distance. This uniform speed is perhaps the greatest defect in the lifting machinery in common use, at least in such lifting machinery as is driven by power.

The lessons of nature in this particular have not been disregarded, however, and we find that the attention of engineers has been given to this principle of variable speed to be controlled at will.

The hydraulic cranes of Sir William Armstrong employ this principle in the most effective manner, not only securing rapid transit of loads when lifted, but depositing or adjusting them with a care and precision unknown to mechanism, that is geared positively or operated by friction breaks.

The principles of all mechanism for handling loads should be such as to place the power, the rate of movement, and the direction of the force, within the control of an operator, which the reader can see is in substance the same thing as the power of the hands.

The safety, simplicity and perfect action of hydraulic machinery has already led its extensive use for moving and lifting weights, and it is fair to assume that the importance and success of this invention fully entitles it to be called one of the most important that has been made in mechanical engineering during the past fifty years.

The application of hydraulic force in operating the machinery used in the Bessemer processes for steel manufacture, is one of the best examples to illustrate the advantages and principles of the system As there are published drawings and descriptions of Bessemer steel plant by Mr. Holly and other engineers, the apprentice is recommended to study the hydraulic apparatus as applied to handling material in these examples, keeping continually in view the principles of action as differing from ordinary cranes or hoists.

There is, however, a defective principle in hydraulic machinery that must be taken into account in comparison with positively geared mechanism, and which in many cases will overbalance any gain derived from its superior action. I allude to the loss of power incident to dealing with an inelastic medium, andwhen the amount of force expended is constant, regardless of the resistance offered. A hydraulic crane, for instance, uses power in proportion to its movement, instead of as the amount of duty performed; it takes the same quantity of water to fill the cylinders, whether the water exert much or little force in moving the pistons, unless the water is drawn from an accumulator that acts by the compression of air, or other elastic fluid.

The difference between employing elastic mediums like air and steam, and an inelastic medium like water for transmitting force in performing irregular duty, has been already alluded to, and forms a very interesting study for a student in mechanics.

The steam cranes of Mr. Morrison that resemble hydraulic cranes, except that steam is employed as the medium for transmitting force, cembine all the advantages of hydraulic apparatus, except positive movement and the difficulties about temperatures, and evade the loss of power that occurs in the use of water. The elasticity of the steam is found in practice to offer no obstacle to steady and accurate movement of a load, provided, the mechanism is well constructed, while the loss by radiation is but trifling.

In manufacturing processes the material operated upon has to be continually moved from one place to another to receive successive operations, and this movement may often be either vertically or horizontally as determined, first, by the relative facility with which the

material may be raised vertically, or moved horizontally, and secondly, by the value of the ground and the amount of room that may be available.

In dense cities where a large share of manufacturing is carried on, the value of the ground is so great that its cost becomes a valid reason for constructing high buildings and moving material vertically by hoists, thus gaining surface by floors, instead of spreading the work over the ground; nor is there any disadvantage in high buildings for most kinds of manufacture, including machine fitting even.

Vertical handling, although it consumes more power, as a rule is more convenient and requires less room than horizontal handling, which is sure to interfere more or less with constructive operations. In machine fitting there is generally a wrong estimate placed upon the value of ground floors, which are no doubt indispensible for the heaviest class of work, and for the heaviest tools, but with an ordinary class of work, where the pieces do not exceed two tons in weight, upper floors if strong are quite as convenient, if there is proper machinery for handling material; in fact the records of any establishment, where cost accounts are carefully made up, will show that the expense of fitting on upper floors is less than on ground floors; this is to be accounted for by better light and a removal of the fitting from the influences and interference of other operations that have to be carried upon the ground floors.

For loading and unloading carts and wagons the convenience of the outside sling is well known; it is also a now attested fact that accidents rarely happen with sling hoists, although they appear to be less safe than running platforms or lifts.

As a general rule the most dangerous machinery for handling or raising material is that which pretends to dispense with the care and vigilance of attendants, and the safest machinery, that which enforce such attention.

The conditions that lead to danger in hoisting machinery, is that the force used is opposed to that of gravity, and as the force of gravity is acting continually, it is always ready to take advantage of the least cessation in the opposing force employed to overpower gravity, and thus drag away the weight for which the two forces are contending, and as a weight when under the influence of gravity is moved at an accelerated velocity, if gravity becomes the master, the result is an accident. Acting on every piece of matter in proportion to its weight, must be some force opposing and equal to that of gravity; a piece of

iron lying on the floor is opposed by the floor and held in resistance to gravity, and to move this piece of iron we have to substitute some living force like that of the hands or lifting mechanism to overcome gravity.

In reasoning in this manner about gravity, it may seem to the apprentice as being a troublesome kind of phenomenon that might be dispensed with, but he must remember that we rely upon gravity to keep things in place, and without it nothing would be fixed.

Reasoning further of gravity, we see that it acts only in one direction—vertically—so that the main force of hoisting and handling machinery which opposes gravity, must also act vertically, while the horizontal movement of weights may be accomplished by simply overcoming the friction between the weights and the surfaces on which they rest.

This is seen in practice; a force of a hundred pounds may move a weight upon a truck, that it would require tons to lift vertically; hence the horizontal movement of material may be easily accomplished by hand with trucks and rollers, so long as it is moved on level planes; but if a weight has to be raised even a single inch by reason of irregularity in floors, we at once feel the difference between overcoming frictional contact and opposing gravity.

One of the principle problems connected with the handling of material is to determine where hand-power should stop and motive-power begin; what conditions will justify the erection of cranes, hoists or tramways, and what conditions will not.

Frequent mistakes are made in the application of power when it is not required; and the too common tendency of the present day being to apply power to every purpose where it is possible, without estimating the actual saving that may be effected. A common impression is that motive power, whenever applied to supplant hand labor in handling material, produces a gain; but the fallacy of this in many cases is apparent, when all the conditions are taken into account.

Considered upon grounds of commercial expediency as a question of cost alone, it is generally cheaper to move material by hand when it can be lifted by workmen, when the movement is mainly in a horizontal direction, and when the labor can be constantly employed; or, to assume a general rule, vertical lifting should be done by motive power, and horizontal movement for short distances performed by hand.

There is nothing more unnatural or wasteful of power than for

men to carry loads up stairs or ladders. The effort expended in such cases is one half or more devoted to raising the weight of the body, which force is not utilized in the descent, and it is always better to use winding or other mechanism for raising weights, even when it is done by manual effort.

Speaking of this matter of carrying loads upward, I am reminded of the fact that builders in England and America, especially in the latter country, often have the material carried up ladders, while in same of the older European countries, where there is but little pretension to scientific manipulation, the bricks are tossed from man to man, and mortar raised by pulleys.

To conclude, the reader will understand that the difficulties and diversity of practice, in any branch of engineering, create similar or equal difficulties in explaining or reasoning about the operations, and the most that could be done in the limited space allotted to the subject of moving material here has been to point out some of the principles that should govern the construction and adaptation of handling machinery, from which the apprentice reader can take up the subject upon his own account, and follow it through the various examples that will come under his notice.

To summarize, we have the following propositions in regard to moving and handling material:

1. The most economical and effectual mechanism for handling is that which places the amount of force and rate of movement continually under the control of an operator.

2. That the necessity for, and consequent saving effected by, power-machinery for handling is mainly in vertical lifting, horizontal movement being easily performed by hand.

3. The vertical movement of material, although it consumes more power, is more economical than horizontal handling, because less floor room and ground surface are required.

4. The value of handling machinery, or the saving it effects, is as the constancy with which it operates; in supplanting hand labor such machinery, may shorten the time of handling without cheapening the expenses.

5. Hydraulic machinery comes nearest to filling the required conditions in handling material, and should be employed in cases where the work is tolerably uniform, and the amount of handling will justify the outlay required for the machinery.

6. Handling material in machine construction is one of the principal

expenses to be dealt with; each time a piece is moved its cost is enhanced, and usually in a much greater degree than is supposed.

7. As the judgment of one man is sufficient to direct handling operations, all the power required in such work, beyond what that one man can exert, should be motive power, if such motive power can be employed for any considerable portion of the time.

8. Power employed in handling material and for other purposes, when it is employed intermittently, must be represented in the motive power, otherwise lifting will interfere with the operation of machines and tools.

Machine Combinations.

The combination of several functions in the same machine, although it may seem an unimportant matter to be considered here, is nevertheless one that has much to do with manufacturing machinery, and constitutes what we may term a principle in construction.

The reasons that favor the combination of several functions in one machine, and the effect that such combination may have on the product of machines, are so various that it has led to a great diversity of opinions and practice among both those who construct and those who employ machines.

It may be said too that a great share of the combinations we see in machines, such as those to turn, mill, and bore, slot and drill in iron fitting, are due not to any deliberate plan on the part of the maker so much as to an opinion that such machines are novel, and represent a double or increased capacity.

So far has this combination in machines been carried, that in one case that came under the writers notice, a machine was arranged to perform nearly every manipulation required in finishing the parts of machinery; completely organized, and displaying a high order of mechanical ability in design and arrangement, but practically of no more value than a single machine tool, because but one operation at a time could be performed.

To direct the attention of the apprentice to certain rules that will guide his opinions and practice in this matter of machine combination, I will present the following propositions and afterwards consider them in detail.

First. By combining two or more operations in one machine the objects gained are economy in framing, the same supports answering double purpose, and a saving of floor room.

Second. In a machine where two or more operations are combined the capacity of such a machine is only as a single one of these operations, unless they can be carried on at the same time without interfering one with the other.

Third. Combination machines can only be used with success when one attendant performs all the operations, and when the change from one operation to another requires but little adjustment and rearrangement in each case.

Fourth. The arrangement of the parts in a combination machine have to be modified by the relations between them, instead of being adapted directly to the nature of the work to be performed.

Fifth. The cost of special adaption and the usual inconvenience of fitting combination machines, when their parts operate independently, generally equals what is saved in framing and floor space.

Referring first to the saving that is effected by combining several operations in one machine, there is perhaps not one constructor in twenty that ever stops to consider what is gained, and perhaps not one purchaser in a hundred that does the same thing. The impression is that when one machine performs two operations it saves a second machine, or several other machines.

A remarkable example of this exists in the manufacture of combination machines for working wood in England, where it is common to find complicated machines that will perform all the operations of a joiner-shop, but as a rule perform one operation at a time, and usually in an inconvenient manner, each operation being hampered and interfered with by another, and in changing from one kind of work to another the adjustments and changes generally equal and sometimes exceed the work to be done. What is stranger still is that such machines are employed when their cost equals that of separate machines to perform the same work.

In metal working, owing to a more perfect division of labor, and a more intelligent manipulation than in wood-working, there is less combination in machines, and is rarely seen at this day, at least in cases where it occasions an actual loss of time or cost.

The advantage of such combinations, as said, can only be in the framing and floor space occupied by the machines, but these considerations, to be estimated by a proper standard, are quite insignificant when compared with other items in the cost of machine operating, such as the attendance, interest on the invested cost of the machine, depreciation of value by wear, repairing and so on.

Assuming that a machine will cost as much as the wages of an attendent for one year, which is not far from an average estimate for iron working machine tools, and that interest, wear, and repairs amount to ten per cent. on this sum, then the attendance would cost ten times as much as the machine; in other words, the wages paid to a workman to attend a machine is on an average ten times as much as the other expenses attending its operation, if we except power.

This assumed, it follows that in machine tools any improvement directed to labor saving will effect *ten times* as much as an equal improvement directed to the economy of first cost or in reducing the instrument.

The same mode of reasoning will lead to a proper estimate of the difference in value between good tools and inferior tools; the results of performance instead of the investment should be considered first because the expenses of operating are, as before said, usually ten times as great as the interest on the investment in a machine itself.

In view of these propositions I need hardly say to what object machine-improvements should be directed, nor which of the considerations named are most affected by a combination of machine functions; the fact is that if careful statistics could be prepared, showing the precise effect on machine combination, it would astonish many who have not investigated the matter, and in many cases would show a loss of the whole cost of the machines each year.

The effect of combinations in machinery is, however, by no means regular, and the remarks made apply to standard machines employed in the regular work of an engineering or othea establishment; in exceptional cases it may be expedient to use combined machines. In the tool room of machine-shops, for instance, where one man can usually perform the main part of the work, and where there is but little space for machines, the conditions are especially favorable to combination machines that may be used in milling, turning, drilling, and so on; but wherever there is a necessity or an opportunity to carry on two or more of these operations at the same time, the cost of separate machines is but a small consideration when compared with the saving of labor that may be effected by independent tools to perform each operation.

The whole tendency of manufacturing processes of every kind, at this day, is to a division of labor, and to separate each operation into as many branches as possible, and study spent in segregating instead of aggregating machine functions is most likely to produce useful results.

I have introduced this article not only to give the learner a true understanding of the effect and value of machine combination, but to caution him against the very common error of confounding machine combination with invention.

A great share of the alleged improvements in machinery when investigated will be found to consist in nothing more than the combination of several functions in one machine, the novelty of their arrangement leading to an impression of utilty and increased effect, but when tried by such standards as have been suggested to determine their value, these supposed improvements will generally be found of no use and not unfrequently a positive disadvantage.

(To be continued.)

ON THE MECHANICAL CALCULATION OF EARTHWORK, (or the Results of Physical Measurements in General), ACCORDING TO THE PRISMOIDAL OR OTHER FORMULAE.

By Clemens Herschell, C. E.

The polar planimeter is an instrument that will, mechanically, find the value of A in the general equation,

$$A = \int F(x)\, dx.$$

It will also, by repeated and consecutive operations, find the value of A, in

$$A = \Sigma \int F(x)\, dx.$$

Finally, by changing the length of the tracing arm, it can be made to find the value of A in the equation

$$A = C\, \Sigma \int F(x)\, dx,$$

where C is any constant.

In ordinary language this means, it will add up the areas multiplied by any constant, of any number of any shaped plane surfaces, and reflection will show how these properties render it capable of solving mechanically many questions, the solution of which would otherwise be very complex. Indeed, it is probable that the full uses of this and other kindred instruments* are yet to be discovered, and that

* A modification of the polar planimeter has been invented that will find the centre of gravity of any figure, its moment of inertia about any line, etc., or generally will solve the equation

$$A = \int F(x)^r\, dx$$

they are destined to be the aids not only of the civil and mechanical engineer, but of all experimenters, who use the exact sciences, in their own peculiar class of investigations.

As an example of what the instrument is capable of, its practical application in the calculation of earthwork, according to the prismoidal formula, will be described.

Written in the form of a series, the prismoidal formula becomes

$$\text{Contents} = \frac{H}{3}\ (S_0 + 4S_1 + 2S_2 + 4S_3 + 2S_4 + \ldots + S_n)$$

where H = the uniform distance from cross-section to cross-section, S_0, $S_1 \ldots S_n$ are the areas of the cross and end sections, and $_n$ must equal an even number.

For earthwork H is usually 100 ft. If the cross-sections are given in square feet, and the answer is desired in cubic yards, the formula becomes, with a few changes,

$$\text{Contents in cubic yds.} = \frac{2 \times 100}{3 \times 27}\Big[\ S_0 + S_1 + S_1 + S_2 + S_3 + S_3 + S_4 + \ldots + S_n - \frac{S_0 + S_n}{2}\Big].$$

This brings the formula into the general shape given above,

$$A = C\ \Sigma \text{ areas},$$

which can be read directly by the planimeter. There remains to be introduced, however, one more constant, namely, the one having reference to the scale in which the cross-sections are submitted for measurement. If this, as is usual on cross-section paper, is 8 ft. = 1 inch, the planimeter, to give A, as above, in cubic yards, will have to read $\frac{2 \times 100 \times 64}{3 \times 27}$ per square inch of paper circumscribed, or, since the circumscribed area is equal to the length of the tracing arm* multiplied by the distance rolled by the wheel, the appropriate length of this arm, to read as above desired, is easily found. Should this length be inconvenient in the manipulation of the planimeter, take, say its double, if that be better, which will result in the final answer being just one-half the true one. If, as the instrument then reads, H, however is taken equal to 50 ft. the final answer will be the true one; if H be equal to 10 ft. it will represent five times the true answer, and so on. These last points become of value in prac-

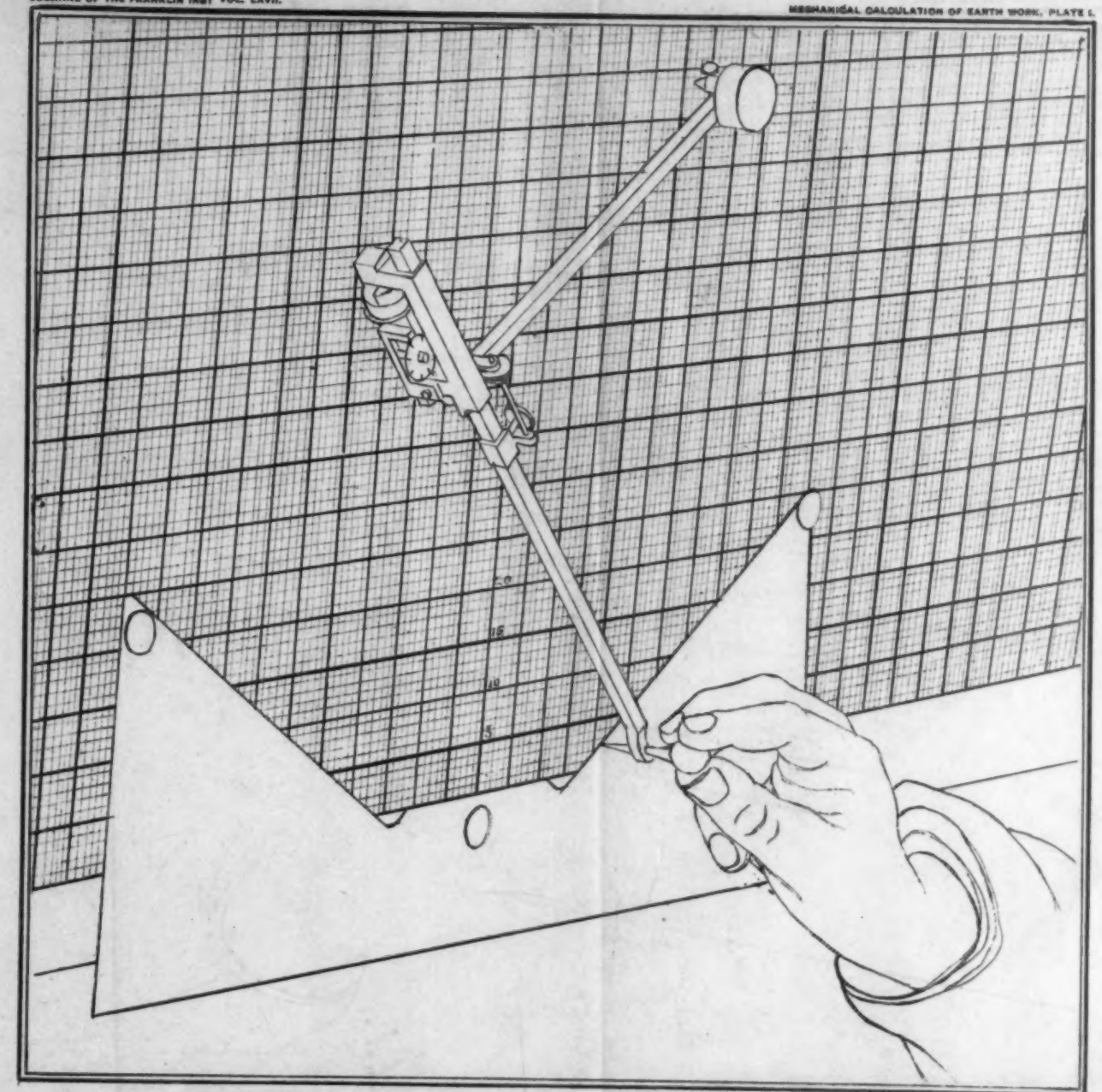
* See, amongst others, Rankine's Civil Engineering, p. 33.

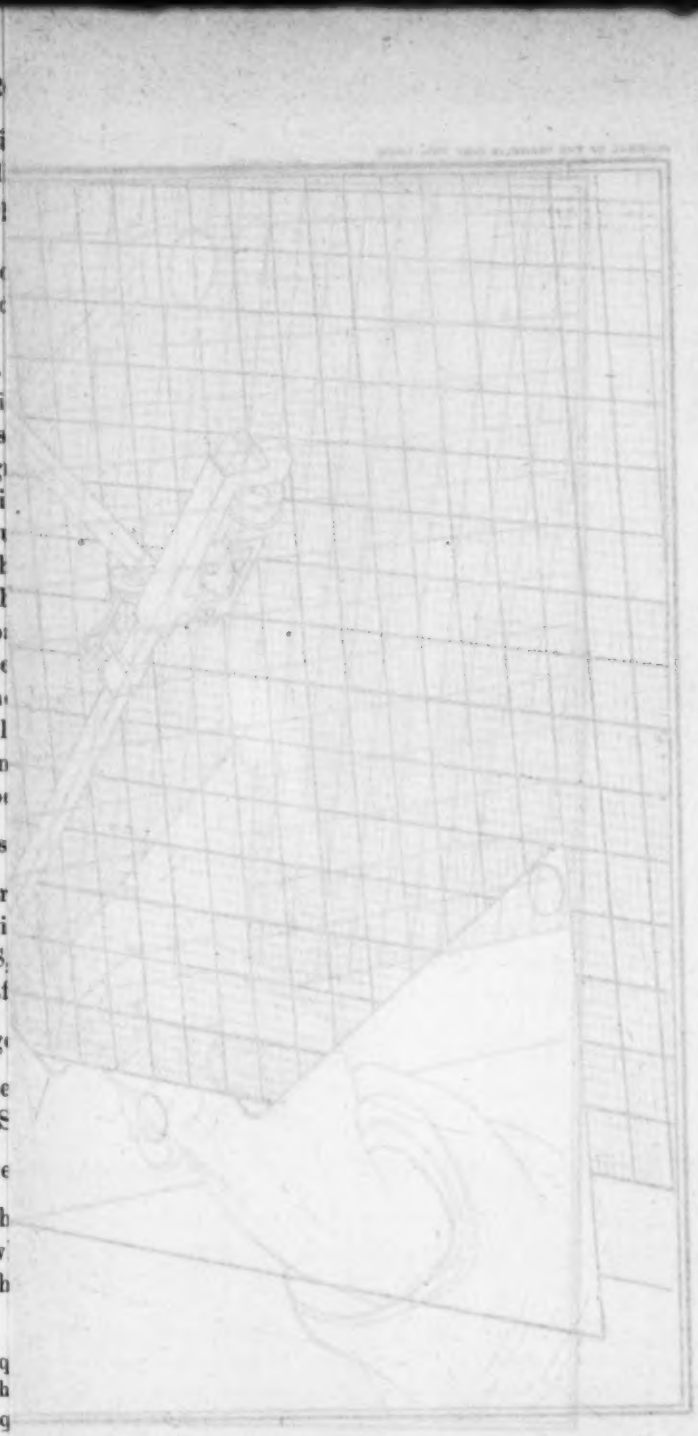
tice in the mechanical calculation of cuts and fills, working from ordinary railroad profiles, as will presently appear. In such cases the operation would be about as follows:

Take a sheet of ordinary cross-section paper, ruled with $\frac{1}{8}$ inch squares;† mark one line of it as the grade line of the cross-sections to be measured.

Figure the centre line heights on the sheet. Next, in the edge of a piece of stiff paper, *cut out*, to a scale of $\frac{1}{8}'' = 1$ ft., the cross-section of a cut and of a fill for the maximum centre or side height that is likely to occur. Laying this down on the ruled sheet with the two grade lines covering one another, we are ready to commence operations. Take a reading of the instrument. An assistant reads off such data as may be in the note book about S_0. Whatever they are, they can be readily taken into account, in moving the tracing arm of the planimeter around a figure representing this cross-section. The pattern is a guide for the tracing point on three sides of the cross-section, the top is read directly on the ruled and numbered sheet beneath, either for centre heights alone, or for side heights in addition, slopes of surface or any other data that may be given. After moving the tracing point around S_0 take another reading. The difference between these two readings gives S_0 multiplied by the constant, which is to be noted, as $\frac{S_0 + S_n}{2}$ multiplied by the constant must be subtracted at the end, according to the formula above written. The assistant next calls off the data for S_1, and that is circumscribed, next S_2, S_3, etc., the instrument doing its own addition. Take a reading after going around S_{n-1}, and again after circumscribing S_n, so as to get the value of S_n for use in $\frac{S_0 + S_n}{2}$. After going through all the sections in this manner keep the crank moving around all the odd S's, (S_1, S_3, S_5 etc.) again. The difference between the first and final readings, minus $\frac{S_0 + S_n}{2}$ found above, is, for H = 100 ft., just half the contents of the cut or fill in cubic yards, with a probable error, which, at present, we find need not be greater than two yards in a thousand, or 0·2 of 1 per cent.

† If the paper has shrunk so that 64 squares do not measure exactly one square inch, but say only ·9 of a square inch, the result obtained from such a sheet must be increased $\frac{1}{9}$, and so on. Or, rule a sheet into squares of exactly $\frac{1}{8}$ square inch and work from that.


0
15
10
5



As railroad and other profiles occur in nature, and because n must be an even number, there will usually be some odd pieces left at each end in passing from cuts to fills and *vice versa*. These are most accurately disposed of by imagining them cut up into 10, 20, 33⅓ ft., or any other even division of 100 feet lengths, then measuring them exactly by the same process as just described, then the answer given by the instrument will be to the true answer as the standard H is to the temporarily assumed H.

It might be argued that this method will still leave some small chips at the ends, but they are evidently of so small moment that they may be neglected. If desired, however, there is, of course, nothing to prevent the sections being taken even every foot in length. Other less exact methods of calculating the end pieces, yet without giving up the advantages derived from the use of the planimeter, are easily devised.

The mechanical method of calculating earthwork, above described, is equal in accuracy to that of the usual operations in the field; it will give results more or less approaching the exact truth, as the latter give more or less data to work from. It is safe to say that no tables yet devised will do anything of the kind for all cross-sections, and when we compare the amount of labor involved in the two methods the contrast is still more glaring. Probably no one who has once tried the planimeter method will again consider the calculation of long lines of earthwork from tables or formulæ as anything else but a species of slavery; for short pieces, though the advantages derived from the former are proportionally less, they are notwithstanding quite as decided. From the few experiments tried in my office I estimate the saving of time derived from the use of the planimeter, over that required by calculating from tables or from formulæ, as ½ to ⅕, according as the cross-sections or note-book data are found tabulated more or less perfectly; the saving in labor is still greater and the gain in accuracy is nevertheless marked and valuable. The degree of accuracy practically attained surpasses what in any ordinary work has hitherto been considered practically attainable.

It would have been just as easy to have made the instrument read cubic yards of contents, according to average end areas, but as the prismoidal formula is much the most accurate, and as one for-formula, when incorporated in the machine involves no more labor than the other, we, of course, prefer the most accurate. The average end area formula, as a series, would read:

$$\text{Contents in cub. yds.} = \frac{100}{27}\left[S_0 + S_1 + S_2 + S_3 + \ldots S_n - \frac{S_0 + S_n}{2}\right]$$

and the proper length of tracing arm can be deduced as before.

These examples will be sufficient to show the wide application that the polar planimeter is probably yet capable of. Such, for example, would be its use as a counter, that will indicate the total horse-power delivered by a steam engine during any period of time, or in friction brake trials, in short for giving the results of a multitude of experiments in civil and mechanical engineering, in acoustics, electricity, and other investigations, say wherever the final result is dependent on any two variables and one or more constants.

Boston, Feb. 21, 1874.

A Lecture Experiment with Potassium.—Mr. H. Kaemmerer communicates the following item to the German Chemical Society, upon a more practical and satisfactory method of showing, experimentally, the green color of potassium vapor. The experiment is generally performed by simply heating a fragment of the metal in a test-tube. In this manner, however, the color of the vapor is only visible for a few seconds, and not at all satisfactorily, inasmuch as its oxidation transpires almost instantly after its formation.

The experiment may be made much finer and upon a larger scale, if the potassium is vaporized in a tube of about a foot in length, placed horizontally, and through which a stream of hydrogen gas is passed during its continuance. Conducted in this way, the experiment is far superior to that first named. The wide tube is speedily filled with the beautiful green vapor of the metal, which deposits itself upon the cool portions of the tube as a lustrous metallic mirror, while the hydrogen escaping from the opposite end (the tube having been drawn out to a narrow opening for the purpose), may be inflamed, and burns with a rich violet light, giving off at the same time thick clouds, from the formation of potassa.

Chemistry, Physics, Technology, etc.

ON THE THERMAL AND MECHANICAL PROPERTIES OF AIR AND OTHER PERMANENT GAS, SUBJECTED TO COMPRESSION OR EXPANSION.

By Professor R. H. Thurston.

[Remark:—Several months ago, a correspondent of the *American Artisan* requested the editor of that periodical to publish a table of pressures and of temperatures due to compression of air up to one-hundred pounds per square inch. The writer was applied to, by the publishers, and soon after supplied such a table in which temperatures, volumes and pressures were given for each five pounds from vacuum up to two hundred pounds per square inch.*

Subsequently a graphical representation of these tables was carefully constructed by a pupil, and very skilfully lithographed, by the American Industrial Publishing Company of New York, for use in the course of instruction at the Stevens Institute of Technology. A reduced copy of these curves was published still later.†

The interest taken by members of the profession and particularly by those engaged in the study of the applications of compressed air and in the development of the hot air engine, and also the investigation of the writer, and his interest in the labors of his colleague, Professor Wood, in the attempt to perfect a new form of rock drill, have induced a more complete examination of the subject; and the preparation of the table here presented, which is probably sufficiently complete to meet all the requirements of engineering practice, and may not require further extension for many years.

The accompanying is a part of a paper prepared in the course of instruction of the engineering classes of the Stevens Institute of Technology, supplementing the instruction obtained from their text books.]

1. When air and other gases are compressed by the application of external force, the mechanical energy, or work done in its compression, takes effect in two ways:—

*American Artisan. March 8th. 1873; page 150.

†Ibid March. 1874.

First, The rate of motion of the particles composing the mass is increased.

Secondly, The relative distances of the particles is diminished.

The first effect becomes evidently an augmentation of temperature, the second, by an increased tension.

By expansion, the potential energy resulting from these two forms of force becomes re-transformed into mechanical work.

2. There are many industrial applications of the phenomena here noted.

The storing of power in compressed air is frequently made essential in mining and tunnelling operations, in which it would be impossible to use steam as a motor for driving engines or working rock drills.

In hot air engines, the increase of tension due to increased temperature, becomes useful in the derivation of mechanical power from thermal action.

In cooling air for ventilating purposes, and frequently in ice-making, the reduction of temperature by the expansion of previously highly compressed air, these thermo-mechanical relations become important.

3. The great and continually increasing importance of these industrial applications, has made the determination of the law of variation of pressure and volume with change of temperature, a matter of great interest to members of the engineering profession as well as to science.

In compressing air for use in mines or in supplying hot air engines, and in ice making and ventilating, also, the heat of compression increasing the tension of the compressed gas, produces a serious addition to the resistance encountered, and since this heat is always partially, and frequently wholly, dissipated without producing useful effect, the consequent loss of efficiency is correspondingly serious.

In compressed air motors, it becomes often more than one-half; and a hundred horse-power expended in driving the compressor, may, when working at great pressures, yield but fifty horse-power, or even twenty-five, of actual useful work.

It is, in such cases, very important to be able to determine the temperature due to the proposed compression in order to estimate the probable amount of this loss.

In the working cylinder of the hot air engine, the communication of heat to the expanding gas produces a tension which should be estimated when the engine is designed, in order to determine the limits both of pressure and temperature, allowable or advisable.

4. Two cases form the limits between which are comprehended all actual examples of change of volume and pressure.

The first case is that in which the temperature of the mass is kept invariable by removing completely the heat of compression or by communication of heat during expansion, as rapidly as becomes necessary to supply that transformed into other forms of energy.

The second case is that in which the change of state, as to pressure and volume, occurs in a perfectly non-conducting chamber, and, consequently, a change of temperature and a modification of the rate of variation of tension noted in the first case may occur.

In all examples met with in the practical work of engineering, the method of variation lies between these limiting cases.

If it be desired to retain the quantity of heat present without change, it is always found impossible to obtain any form of apparatus which is impervious to heat and which will absolutely prevent a flow of heat into, or out of, the air reservoir.

The air also contains, invariably, a considerable amount of the vapor of water which, having a comparatively great capacity for heat, will produce a marked alteration of temperatures as observed with dry air.

If it be desired to absorb the heat of compression, and to keep the temperature of the mass perfectly invariable, as in the first of the two representative cases, it will always be found impossible to obtain a perfectly efficient method of securing a sufficiently rapid outflow of heat from the gas undergoing compression, both because of the impossibility of finding a perfect conductor of heat and of the fact that air and other gases are exceedingly imperfect transfers of heat, being apparently absolute non-conductors.

All actual cases, therefore, are intermediate between the two here considered, and only experience and a trained judgment can be relied upon to estimate the true conditions in any individual example.

5. Case 1st, is that to which that law applies which was discovered independently by the English philosopher Boyle and the French *savan* Marriotte, viz: "*The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure.*"

Assuming one hundred volumes of air, originally of mean atmospheric pressure, 14·7 pounds per square inch, to undergo change of pressure and volume, the relation of pressure and volume is expressed by the equation, $PV=P^1V^1$; and, for this case, $PV=1470$, hence

$$V = \frac{1470}{P} \qquad (1)$$

where P^1 and P are the pressure in pounds per square inch above a vacuum, and where V^1 and V are the volumes.

Regnault, who made the most elaborate and accurate research in this direction, found that the permanent gases followed this law very closely, although not precisely, while the liquefiable gases departed from it more considerably.

The permanent gases, including air, deviate so slightly from the law that Dulong and Arago, who compressed air to 27 atmospheres pressure, were unable to detect the deviation afterwards discovered by Regnault.

For all ordinary cases of application the law may be assumed exact, and it is so assumed in the table here given.

6. Case 2D,—or that in which a change of volume, pressure and temperature occurs without transmission of heat into, or out from, the mass,—requires, for its complete examination, a determination of the specific heat of the gas, both under constant pressure and constant volume, and of its co-efficient of expansion, and a knowledge of the mechanical equivalent of heat.

The specific heat of air was determined by De la Roche and Berard, by De la Rive and Marcet, and finally, with greatest probable accuracy, by Regnault. It has the value, under constant pressure, of 0·2379, water being taken as the standard, and its specific heat being 1.

The specific heat of a gas under constant volume has not been determined by direct means, but, by an indirect determination based on the acceleration of the velocity of sound due to changes of temperature produced by alternate expansion and contraction, it has been found to have a ratio to specific heat under constant pressure of 1·408 to 1.

The co-efficient of expansion of air, as determined by Regnault, is found to be ·003665 for the centigrade scale or ·002036 for Fahrenheit degrees.

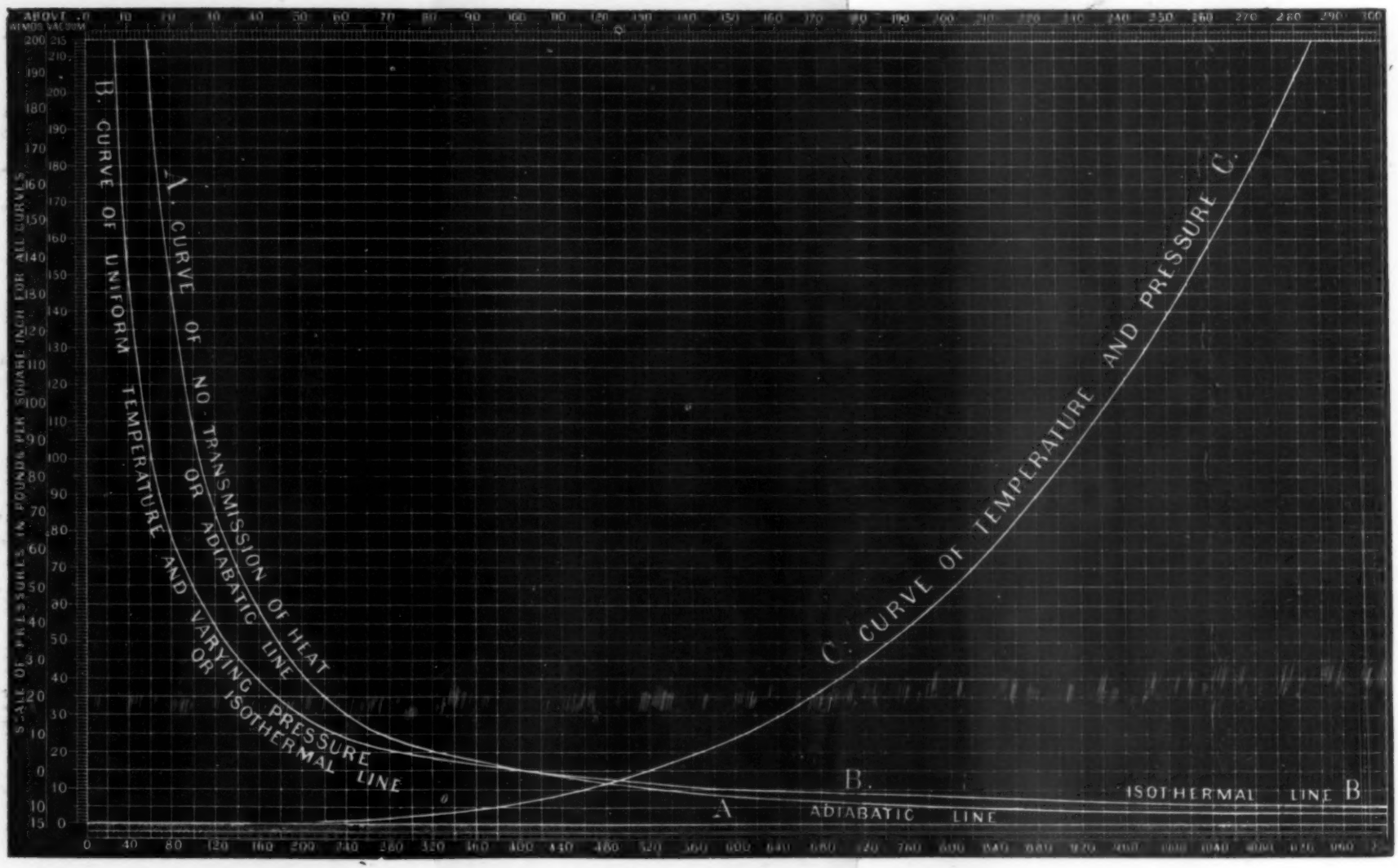
The specific heat of air seemed to be constant for all pressures. The co-efficient of expansion varies slightly, but not sufficiently to make it necessary to consider that variation in this paper.

The data for calculating the mechanical equivalent of heat were first given approximately by Rumford in 1798, in the paper* in which

* Phil. Trans. Royal Soc. 1798; also, Trans. Am. Society of Civil Engineers, 1873. Art. 67.

Graphical Representation of the Thermal and Mechanical Properties of Air and Permanent Gases, by Professor Thurston.

SCALE OF VOLUME FOR CURVES A A AND B B.


ABOVE
B. CURVE OF UNIFORM TEMPERATURE AND VARYING PRESSURE OR ISOTHERMAL LINE
A. CURVE OF NO TRANSMISSION OF HEAT OR ADIABATIC LINE
C. CURVE OF TEMPERATURE AND PRESSURE C.
B.
ISOTHERMAL LINE B
A
ADIABATIC LINE

ABSOLUTE SCALE OF TEMPERATURES FOR CURVE C C'. IN FAHRENHEIT DEGREES. DEDUCT 461.2 FOR COMMON SCALE.

The pressure being given, to determine the coincident volume, when the mass consisted originally of 100 volumes at atmospheric temperature and density:—

Follow a line parallel with the base line, from its intersection with the given pressure on the scale, to its intersection with the adiabatic, or curve of no transmission of heat, for ordinary cases, or, with the isothermal line when the temperature of the air remains perfectly uniform; thence follow a vertical line upward to the scale where the required volumes can be read off.

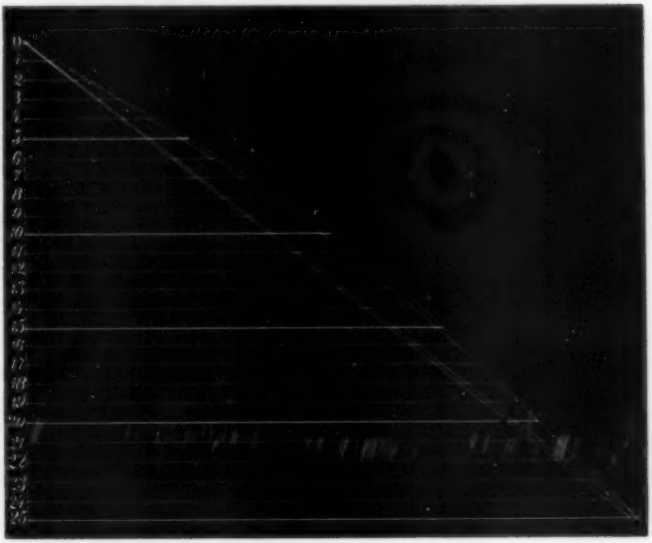
The reverse of this operation gives the change of pressure, the alterations of volume being known.

To find the temperature due a given degree of compression: Find coincident readings on the scale of temperature and pressure for the proper point on the curve, C.

Jour. Frank. Inst. Vol. LXVII. Mech. and Thermal Prop. of Air, Plate II.

Curves exhibiting the agreement of the experimental determination of Capt. Ericsson with the estimates of R. H. Thurston.

PREPARED BY CAPT. JOHN ERICSSON, NEW YORK, 1874.



Ordinates of dotted line represent increments of temperature by compression above the atmosphere, as ascertained by Ericsson.

Ordinates of continuous line represent temperature estimates by Thurston.

Marginal figures repre-ent tension of compressed air in pounds per square inch above atmosphere.

* See TAIT; Sketch of Thermodynamics. London, 1868.

† Steam Engines and Prime Movers.

he announced the now well-known fact that heat and mechanical energy are simply two methods of manifestation of force, and are mutually convertible. Mayer and Joule, in 1842 and 1843, independently determined it, and the experimental investigations of the latter are now relied upon as giving very accurately its value. The accepted value is 772 foot pounds as the equivalent of the British thermal unit, and 1389·6 foot pounds for the French *caloric*.

Clausius, Rankine, Thompson and Zeuner have based upon these experimental determinations a branch of this science of energetics, which is known as "Thermodynamics" The first two named, independently constructed the general equation of thermodynamics, which is an algebraic expression of the mutual relations of thermal and mechanical energy, and embodies the fundamental principles of the science.*

The equations representing the relations of pressure, temperature and volume of air and the permanent gases, as deduced by these authorities, and as given by Rankine,† is

$$\frac{\tau}{\tau_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} \qquad (2)$$

in which τ_1, τ_2, v_1, v_2, p_1, p_2, are the absolute temperatures, the volumes and the pressures of the gas, and γ represents the ratio of the specific heat of constant pressure to the specific heat of constant volume. The latter ratio is that of the energy required to change the state of the gas as to temperature merely to that required to effect both a change of temperature and of intrinsic energy.

From (2) we obtain

$$p \propto \frac{1}{v^{\gamma}} \qquad (3)$$

The values of the several exponents for air are $\gamma = 1{\cdot}408$, $\gamma-1 = 0{\cdot}408$ and $\frac{\gamma-1}{\gamma} = 0{\cdot}29$, as given by Rankine, and deduced from Regnault, Magnus and Rudberg.

From these equations, and equation 1 previously given, the values given in the following table are obtained. They are determined for a wider range than will probably be required in any engineering estimates.

* See TAIT; Sketch of Thermodynamics. London, 1868.
† Steam Engines and Prime Movers.

8. The graphical representation of Case 1st, which case is given numerically in column C of the table, is an "isothermal line."

The curve representing the relative values of pressure and volume under Case 2d is an "adiabatic line."

These two lines, as well as the graphic representation of the changes of pressure and temperature, are seen in the accompanying large plate as they were beautifully reduced for the *American Artisan*.

The curves here given exhibit to the eye the very considerable difference in pressures resulting from similar changes of volume in the two representative cases, and illustrate well the fact that, in the use of compressed air for transmission of power, the loss of efficiency must be very serious, when, as is almost invariably the case, the heat of compression is not removed as produced.

At low pressures even, the losses of heat, or by its removal by special provisions, are exceedingly small, as is shown by the accompanying pair of curves (Plate II), prepared for the writer, by Captain Ericsson, to illustrate the close correspondence between the pressures and temperatures noted by him during his experiments, extending, as he states, over a series of years, and the estimates here presented.

At five pounds above the atmosphere, the difference is given as $\frac{1}{115}$, at ten pounds $\frac{1}{37}$, at fifteen pounds $\frac{1}{90}$, at twenty pounds the figures coincide perfectly, and at twenty-five pounds the discrepancy is $\frac{1}{68}$.

The experimenter, in the letter accompanying this comparative statement, says:

"In view of the loss of heat by radiation, the close agreement between theory and practice will surprise those who do not consider that, during the first portion of the stroke of the piston, the confined air, before attaining maximum tension, receives much heat from the cylinder.

"Indeed, but for the fact that the heating of the air, and consequent expansion while being drawn into the cylinder, prevents a full supply of air of atmospheric density, this increment of pressure attained in practice would greatly exceed the theoretical determination."

Professor Frazier has made a mathematical investigation of the amount of energy expended in compressing air and working the compressed fluid,* and gives the following:

*Engineering and Mining Journal, July, 1873.

TABLE OF PRESSURES, TEMPERATURES AND VOLUMES OF COMPRESSED AIR AND PERMANENT GASES. Prepared by Professor R. H. THURSTON, OF THE STEVENS' INSTITUTE OF TECHNOLOGY.*

One hundred volumes of air at atmospheric mean temperature (60° Fahr.), and pressure (14·7 lbs. per square inch) undergoes change of volume without gain or loss of heat.

The resulting temperatures and volumes are entered in columns B, C, D, E and F, and the pressures in columns A and H.

An equal quantity is similarly compressed, but with its temperature maintained at 60° Fahr. The resulting changes of volume are given in column G.

Temperatures are measured in Fahrenheit degrees, and are reckoned from the absolute zero in column B, and from the zero of Fahrenheit's scale in column C.

Temperatures are measured in Centigrade degrees, and reckoned from the absolute zero in column D, and from the zero of the Centigrade scale in column E.

Pressures are given in pounds per square inch above vacuum in column A, and above a point fifteen pounds higher in column H, the latter standard being approximately the atmospheric tension.

The weight of one cubic foot of air, as taken at mean atmospheric pressure and temperature, is 0·076,391 pounds avoirdupois. At the freezing point it is 0·080,728 if at atmospheric pressure, its weight varying, under constant pressure, inversely as the absolute temperature.

Pressures. lbs. p. sq. in.	Temp. (Fah. deg.) above.		Temp. (Cent. deg.) above		Volumes with Temp.		Pressures. Column A—15 lbs.	Pressures. lbs. p. sq. in.	Temp. (Fah. deg.) above.		Temp. (Cent. deg. above)		Volumes with Temp.		Pressures. Column A—15 lbs.
	Absolute zero.	Fah. zero.	Absolute zero.	Cent. zero.	Variable.	Constant.			Absolute zero.	Fah. zero.	Absolute zero.	Cent. zero.	Variable.	Constant.	
A.	B.	C.	D.	E.	F.	G.	H.	A.	B.	C.	D.	E.	F.	G.	H.
0	0	—461·20	0	—274·00	Infinite.	Infinite.	—15	111	936·76	475·56	520·41	246·41	23·80	13·24	96
1	+239·05	—222·15	+132·8	—141·19	674·21	1470·00	—14	112	939·20	478·00	521·77	247·77	23·65	13·12	97
2	292·27	—168·93	162·16	—111·64	411·21	735 00	—13	113	941·62	480·42	523·12	249·12	23·50	13·01	98
3	328·73	—132·47	182·63	—91·37	309·06	490·00	—12	114	944·03	482·83	524·46	250·46	23·35	12·90	99
4	357·34	—103·86	198·53	—75·47	251·96	367·50	—11	115	946·42	485·22	525·79	251·79	23·21	12·79	100
5	381·22	—79·98	211·79	—62·21	215·04	294·00	—10	116	948·80	487·60	527·11	253·11	23·07	12·68	101
6	401·93	—59·27	223·29	—50·71	188·93	245·00	—9	117	951·17	489·97	528·42	254·42	22·93	12·57	102
7	420·50	—40·90	235.72	—38·28	169·35	210·00	—8	118	953·52	492·32	529·73	255·73	22·79	12·46	103
8	436·55	—24·65	242·53	—30·47	154·03	185·00	—7	119	955·85	494·65	531·02	257·02	22·65	12·35	104
9	452·08	—9·12	251·16	—22·84	141·62	163·33	—6	120	958·17	496·97	532·31	258·31	22·52	12·25	105
10	466·10	+4·90	258·94	—15·06	131·46	147·00	—5	121	960·48	499·28	533·61	259·61	22·39	12·15	106
11	479·26	18·06	266·26	—7·74	122·86	133·64	—4	122	962·78	501·58	534·87	260·87	22·26	12·05	107
12	491·41	30·21	273·02	+3.02	115·50	122·50	—3	123	965·06	503·86	536·15	262·15	22·13	11·95	108
13	502·95	41·75	279·41	5·41	109·12	113·08	—2	124	967·33	506·13	537·41	263·41	22·00	11·85	109
14	513·88	52·69	285·49	8·87	103·53	105·00	—1	125	969·59	508·39	538·66	264·66	21·88	11·76	110
15	524·26	63·16	291·26	17·26	98·58	98·00	0	126	971·83	510·63	539.91	265·91	21·76	11·67	111
16	534 17	72·97	296·76	22·76	94·16	91.88	+1	127	974·06	512·86	541.15	267·15	21·64	11·57	112
17	543·64	82·44	302·02	28·02	90·19	86·47	2	128	976·28	515·08	542·37	268·37	21·52	11·48	113
18	552·73	91·53	307·07	33·07	86·61	81·07	3	129	978·49	517·29	543·70	269·60	21·40	11·39	114
19	561·47	100·27	311·93	37·93	83·35	77·37	4	130	980·68	519·48	544·82	270·82	21·28	11·31	115
20	569·88	108·76	316·60	42·60	80·36	73·50	5	131	982·86	521·66	546·03	272·03	21·16	11·22	116
21	578·00	116·80	321·11	47·11	77·63	70·00	6	132	985·03	523·83	547·24	273 24	21·04	11·14	117
22	585·85	124·65	325·47	51·42	75·11	66·82	7	133	987·19	525·99	548·38	274·38	20·92	11·05	118
23	593·45	132·25	329·69	55·69	72·77	63·91	8	134	989·33	528·13	549·62	275·62	20·81	10·97	119
24	600·82	139·62	333·79	59·79	70·61	61·25	9	135	991·47	530·27	550·81	276·81	20·71	10·89	120
25	607·97	146·77	338·76	64·76	68·59	58·80	10	136	993·59	532·39	551·96	277·96	20·60	10·81	121
26	614·93	153·73	341·63	67·63	66·71	56·54	11	137	995·71	534 51	553·17	279·17	20·49	10·73	122
27	621·70	160·50	345·38	71·38	64·94	54·44	12	138	997·81	536·61	554·34	280·34	20·39	10·65	123
28	628·29	167·09	349·05	75·05	63·29	52·50	13	139	999·90	538·70	555·50	281·50	20·29	10·57	124
29	634·71	173·51	352·61	78·61	61·73	50·69	14	140	1001·98	540·88	556·66	282·66	20·19	10·50	125
30	640·98	179·78	356·10	82·10	60·27	49·00	15	141	1004·05	542·95	557·31	283·31	20·09	10·43	126
31	647·11	185·91	359·51	85·51	58·88	47·42	16	142	1006·11	544·91	558·95	284 95	19·99	10·35	127
32	653·09	191·89	362·83	88·83	57·56	45·94	17	143	1008·16	546·96	560·09	286·09	19·90	10·28	128
33	658·95	197·75	366·08	92·08	56·32	44·55	18	144	1010·20	549·00	561·22	287·22	19·79	10·21	129
34	664·68	203·48	369·26	95·26	55·14	43·23	19	145	1012·23	551·03	562·35	288·35	19·69	10·14	130
35	670 29	209·19	372·38	98.38	54·01	42·00	20	146	1014·25	553·05	563·47	289·47	19·59	10·07	131
36	675·79	214·59	375·44	101·44	52·94	40·83	21	147	1016·26	555·06	564·59	290·59	19·49	10·00	132
37	681·02	219·82	378·34	104·34	51·93	39·73	22	148	1018·26	557·06	565·70	291·70	19·40	9·93	133
38	686·47	225·27	381·37	107·34	50·95	38·68	23	149	1020.25	559·05	566·81	292·81	19·31	9·86	134
39	691·66	229·82	384·26	110·26	50·01	37·69	24	150	1022·23	561·03	567·91	293·91	19·22	9·80	135
40	696.75	235·55	387·06	113·86	49·13	36·75	25	151	1024·20	563·00	569·00	295·00	19·13	9·73	136
41	701·76	240·56	389·86	115·86	48·28	35·85	26	152	1026·16	564·96	570·09	296·00	19·04	9·67	137
42	706·68	245·28	392·60	118·60	47·46	35·00	27	153	1028·12	566·92	571·18	297·18	18·95	9·61	138
43	711·52	250 32	395·29	121·29	46·66	34·19	28	154	1030·06	568·86	572·26	298·26	18·86	9·55	139

19	561·47	100·27	311·93	37·93	83·35	77·37	4	130	980·68	519·48	544·82	270·82	21·28	11·31	115
20	569·88	108·76	316·60	42·60	80·36	73·50	5	131	982·86	521·66	546·03	272·03	21·16	11·22	116
21	578·00	116·80	321·11	47·11	77·63	70·00	6	132	985·03	523·83	547·24	273 24	21·04	11·14	117
22	585·85	124·65	325·47	51·42	75·11	66·82	7	133	987·19	525·99	548·38	274·38	20·92	11·05	118
23	593·45	132·25	329·69	55·69	72·77	63·91	8	134	989·33	528·13	549·62	275·62	20 81	10·97	119
24	600·82	139·62	333·79	59·79	70·61	61·25	9	135	991·47	530·27	550·81	276·81	20·71	10·89	120
25	607·97	146·77	338·76	64·76	68·59	58·80	10	136	993·59	532·39	551·96	277·96	20·60	10·81	121
26	614·93	153·73	341·63	67·63	66·71	56·54	11	137	995·71	534 51	553·17	279·17	20·49	10·73	122
27	621·70	160·50	345·38	71·38	64·94	54·44	12	138	997·81	536·61	554·34	280·34	20·39	10·65	123
28	628·29	167·09	349·05	75·05	63·29	52·50	13	139	999·90	538·70	555·50	281·50	20·29	10·57	124
29	634·71	173·51	352·61	78·61	61·73	50·69	14	140	1001·98	540·88	556·66	282·66	20·19	10·50	125
30	640·98	179·78	356·10	82·10	60·27	49·00	15	141	1004·05	542·95	557·31	283·31	20·09	10·43	126
31	647·11	185·91	359·51	85·51	58·88	47·42	16	142	1006·11	544·91	558·95	284 95	19·99	10·35	127
32	653·09	191·89	362·83	88·83	57·56	45·94	17	143	1008·16	546·96	560·09	286·09	19·90	10·28	128
33	658·95	197·75	366·08	92·08	56·32	44·55	18	144	1010·20	549·00	561·22	287·22	19·79	10·21	129
34	664·68	203·48	369·26	95·26	55·14	43·23	19	145	1012·23	551·03	562·35	288·35	19·69	10·14	130
35	670 29	209·19	372·38	98.38	54·01	42·00	20	146	1014·25	553·05	563·47	289·47	19·59	10·07	131
36	675·79	214·59	375·44	101·44	52·94	40·83	21	147	1016·26	555·06	564·59	290·59	19·49	10·00	132
37	681·02	219·82	378·34	104·34	51·93	39·73	22	148	1018·26	557·06	565·70	291·70	19·40	9·93	133
38	686·47	225·27	381·37	107·34	50·95	38·68	23	149	1020.25	559·05	566·81	292·81	19·31	9·86	134
39	691·66	229·82	384·26	110·26	50·01	37·69	24	150	1022·23	561·03	567·91	293·91	19·22	9·80	135
40	696.75	235·55	387·06	113·86	49·13	36·75	25	151	1024·20	563·00	569·00	295·00	19·13	9·73	136
41	701·76	240·56	389·86	115·86	48·28	35·85	26	152	1026·16	564·96	570·09	296·00	19·04	9·67	137
42	706·68	245·28	392·60	118·60	47·46	35·00	27	153	1028·12	566·92	571·18	297·18	18·95	9·61	138
43	711·52	250 32	395·29	121·29	46·66	34·19	28	154	1030·06	568·86	572·26	298·26	18·86	9·55	139
44	716·28	255·08	397·93	123 93	45·90	33·41	29	155	1031·99	569·79	573·33	299·33	18·77	9·48	140
45	720·97	259 77	400.54	126·54	45·18	32·67	30	156	1033·92	571·72	574·40	300·40	18·68	9·42	141
46	725·58	264·38	403·10	129·10	44.49	31·96	31	157	1035.84	574·64	575·46	301·46	18·60	9·36	142
47	730·12	268·92	405·62	131·54	43·82	31·28	32	158	1037·75	576·55	576.52	302·52	18·52	9·30	143
48	734·59	273·39	408·11	134·11	43·16	30·63	33	159	1039·15	578·45	577·58	303·58	18·44	9·24	144
49	738·99	277·79	410·55	136·55	42·54	30·00	34	160	1041·54	580·34	578·63	304·63	18·36	9·19	145
50	743·33	282·13	412·96	138·96	41·93	29 40	35	161	1043·43	582·23	579·68	305·68	18·28	9·13	146
51	747·62	286·42	115·35	141·35	41·35	28·82	36	162	1045·30	584·10	580·72	306·72	18·20	9·07	147
52	751·84	290·64	417·69	143·69	40·78	28·27	37	163	1047·17	585·97	581·76	307·76	18·12	9·02	148
53	756·00	294·80	420·00	146·00	40·23	27·74	38	164	1049·03	587·83	582·79	308·79	18·04	8·97	149
54	760·11	298·91	422·28	148·28	39·70	27·22	39	165	1050 88	589·68	583·82	309·82	17·96	8·91	150
55	764·16	302·96	424.53	150·53	39·19	26·73	40	166	1052·72	591·52	584·79	310·79	17·88	8·86	151
56	768·17	306·97	426·76	152·76	38·69	26·23	41	167	1054·25	593·05	585·65	311·69	17·80	8·81	152
57	772·12	310·92	428·96	154·96	38·21	25·78	42	168	1056·38	595·18	586·87	312·87	17·72	8·75	153
58	776·03	314·83	431·12	157·12	37·74	25·34	43	169	1058·20	597·00	587·89	313·89	17 65	8·70	154
59	779·88	318·68	433·26	159·26	37·28	24·95	44	170	1060·01	598·82	588·90	314·90	17·58	8·65	155
60	783·69	322·17	435·38	161·38	36·84	24·50	45	171	1061·82	600·62	589·90	315·90	17·51	8·60	156
61	787·46	326·26	437·47	163·47	36·41	24·09	46	172	1063·62	602·42	590·90	316·90	17·44	8·55	157
62	791·18	329·98	439·54	165·54	35·99	23·71	47	173	1065·41	604·21	591·89	317·89	17·37	8·50	158
63	794·86	333·66	441·59	167·59	35·59	23·33	48	174	1067·19	605·99	592·88	318·88	17·30	8·45	159
64	798·50	337·30	443·61	169·61	35·19	22·97	49	175	1068·97	607·77	593·87	319·87	17·23	8·40	160
65	802·10	340·90	445·61	171·61	34·80	22·62	50	176	1070·74	609·54	594·86	320·86	17·16	8·35	161
66	805·66	344·46	447·59	173·59	34·43	22·27	51	177	1072·49	611·29	595·82	321·82	17·09	8·30	162
67	809·18	348·98	449·54	175·96	34·06	21·94	52	178	1074·44	613·24	596·80	322 80	17·02	8·26	163
68	812 66	351·46	451·48	177·48	33·71	21·62	53	179	1075·98	614·78	597·76	323·76	16·95	8·21	164
69	816·11	354·91	453·39	179·39	33·36	21·30	54	180	1077·72	616·51	598·72	324·72	16·89	8·17	165

65	802·10	340·90	445·61	171·61	34·80	22·62	50	176	1070·74	609·54	594·86	320·86	17·16	8·35	161
66	805·66	344·46	447·59	173·59	34·43	22·27	51	177	1072·49	611·29	595·82	321·82	17·09	8·30	162
67	809·18	348·98	449·54	175·96	34·06	21·94	52	178	1074·44	613·24	596·80	322 80	17·02	8·26	163
68	812 66	351·46	451·48	177·48	33·71	21·62	53	179	1075·98	614·78	597·76	323·76	16·95	8·21	164
69	816·11	354·91	453·39	179·39	33·36	21·30	54	180	1077·72	616·51	598·72	324·72	16·89	8·17	165
70	819·52	358·32	455·29	181·29	33·02	21·00	55	181	1079·46	618·26	599·70	325·70	16·82	8·12	166
71	822·90	361·70	457·16	183·16	32·69	20·70	56	182	1081·19	618·99	600·66	326·66	16·75	8·07	167
72	826·24	365·04	459·02	185·02	32·37	20·42	57	183	1082·91	621·71	601·61	327·61	16·68	8·03	168
73	829·56	368·36	460·86	186 86	32·05	20·13	58	184	1084·62	623·42	602·56	328·56	16·62	7·99	169
74	832·84	371·64	462·69	188·69	31·74	19·86	59	185	1086·33	625·13	603 51	329·51	16·56	7·95	170
75	836·08	374·88	464·49	190·49	31·44	19·60	60	186	1088·03	626·83	604·46	330·46	16·50	7·90	171
76	839·30	378·10	466·27	192 27	31·15	19·34	61	187	1089·72	628 52	605·40	331·40	16·44	7·86	172
77	842·49	381·29	468·05	194·05	30·86	19·09	62	188	1091·41	629·21	606·34	332·34	16·38	7·82	173
78	845·65	384·45	469·81	195·81	30·58	18·84	63	189	1093·09	631·89	607·24	333·27	16·32	7·78	174
79	848·78	387·58	471·54	197·54	30·30	18·61	64	190	1094·77	633·57	608·24	334·24	16·26	7·74	175
80	851·88	390·68	473·26	199·26	30·03	18·38	65	191	1096·44	635·24	609·14	335·14	16·20	7·70	176
81	854·96	393·76	474·97	200·97	29·77	18·15	66	192	1098·10	636·90	610·05	336·05	16·14	7·66	177
82	858·00	396·80	476·66	202·66	29·51	17·93	67	193	1099·75	638·55	610·97	336·97	16·08	7·62	178
83	861·05	399.85	478·36	204·36	29·26	17·71	68	194	1101·40	640·20	611·89	337·89	16·02	7·58	179
84	864· 2	402·82	480·01	206·01	29·01	17·50	69	195	1103·04	641·84	612·81	338·81	15·96	7·54	180
85	866·99	405 79	481·66	207·66	28.77	17·29	70	196	1104·68	643·48	613·71	339·71	15·90	7·50	181
86	869·94	408·74	483·30	209·30	28·53	17·09	71	197	1106·31	645·11	614·61	340·61	15·84	7·46	182
87	872·86	411·66	484·81	210·81	28·30	16·89	72	198	1107·94	646·74	605·52	341·52	15·78	7·42	183
88	875·76	414·56	486·53	212·53	28·07	16·70	73	199	1109 56	648·36	616·42	342·42	15·72	7·38	184
89	876·63	415·43	487·01	213·01	27·84	16·51	74	200	1111·17	649·97	617·31	343·31	15·67	7·35	185
90	881·48	420·28	488·71	214·71	27·62	16·33	75	205	1119·16	657·96	621·75	347·75	15·40	7·17	190
91	884·31	423·11	491·28	216·28	27·41	16·15	76	210	1127·00	665·80	626·11	352·11	15·14	7·00	195
92	887·12	425·92	492·85	218·85	27·20	15·98	77	215	1134 72	673·52	630·38	356·38	14·89	6·84	200
93	889·90	428·70	494·39	220·39	26·99	15·81	78	220	1142·32	681·12	634·62	360·62	14·64	6·68	205
94	892·67	431·47	495·92	221 92	26·78	15·64	79	225	1149·78	688·58	638·71	364·71	14·41	6·53	210
95	895·41	434·21	497·45	223·45	26·58	15·47	80	230	1157·13	695·93	644·35	370·35	14·19	6·39	215
96	898·14	436 94	498·96	224·96	26·39	15·31	81	235	1164·37	703·17	646·87	372·87	13·98	6·26	220
97	900·84	439·64	500·46	226·46	26·19	15·15	82	240	1171·50	710 30	650·83	376·83	13·77	6·13	225
98	903·52	442·32	501·96	227·96	26·00	15·00	83	245	1178·52	717·32	654·73	380·63	13·57	6·00	230
99	906·18	444·98	503·43	229·43	25·82	14·85	84	250	1185·43	724·23	685·57	411·57	13·38	5·88	235
100	908·83	447·63	504·91	230·91	25·63	14·70	85	300	1249·82	788·62	694·34	420·34	11·75	4·90	285
101	911·46	450·26	506·16	232·16	25·45	14·55	86	350	1306·96	845·76	726·09	452·09	10·59	4·20	335
102	914·07	452·87	507·81	233·81	25·28	14·41	87	400	1358·56	897·36	754·76	480·76	9·58	3·90	385
103	916 65	455·45	509·25	235·25	25·10	14·27	88	450	1405·77	944·57	780·98	506·98	8·81	3·27	435
104	919·22	458·02	510·68	236·68	24·93	14·13	89	500	1449·38	988·28	805·21	531·21	8·17	2·94	485
105	921·78	460·58	512·10	238·10	24·76	14·02	90	600	1528·08	1066·88	848·93	574·93	7·18	2 45	585
106	924·32	463·12	513·51	239·51	24·59	13·87	91	700	1597·94	1136·74	887·74	603·74	6·44	2·10	685
107	926·84	465·64	514·91	240·91	24·43	13·74	92	800	1661·04	1199·84	922·80	648·80	5·86	1 84	785
108	929·34	468·14	516·30	242·30	24·27	13·61	93	900	1718·75	1257·55	954·86	680·86	5·39	1·63	885
109	931·83	470·63	517·68	243·68	24·11	13·48	94	1000	1772·08	1310·88	984·49	710·49	5·00	1·47	985
110	934·30	473·10	519·06	245·06	23·96	13·36	95	2000	2166·61	1705·41	1203·67	929·67	3·06	0·74	1985

* Entered according to act of Congress in the year 1874, in the Office of the Librarian of Congress at Washington.

TABLE SHOWING PROPORTION OF WORK LOST.

Absolute working pressure in atmospheres.	With full expansion.		With no expansion.	
	Air completely cooled in compressor.	Air not cooled in compressor.	Air completely cooled in compressor.	Air not cooled in compressor.
2	0·09	0·18	0·28	0·35
3	0·14	0·27	0·39	0·48
4	0·18	0·33	0·46	0·56
5	0·20	0·37	0·50	0·61
6	0·22	0·40	0·53	0·65
7	0·24	0·43	0·56	0·67
8	0·25	0·45	0·58	0·69
9	0·26	0·47	0·60	0·71
10	0·27	0·49	0·61	0·73

The importance of removing the heat of compression as completely as possible, and simultaneously with its production, is here well shown, as well as by the table and diagrams above given. Were it possible to retain completely this transformed energy, the economical result would evidently be still more satisfactory, however, and the devising of efficient means of utilizing these two methods of avoiding a now serious loss, in all cases of air compression, is a very important engineering problem.

Stevens Institute of Technology, Hoboken, N. J., Feb., 1874.

ON THE STRENGTH, ELASTICITY, DUCTILITY AND RESILIENCE OF MATERIALS OF MACHINE CONSTRUCTION,

And on Various Hitherto Unobserved Phenomena, Noticed during Experimental Researches with a New Testing Machine, fitted with an Autographic Registry.

By Prof. R. H. Thurston.

Read before American Society of Civil Engineers, Feb. 4, 1874.

Section I.

1. Introductory.*—Some months ago, while engaged with the advanced classes of the Stevens Institute of Technology, in experimental investigations of the resistance of materials, it was found that coëfficients were given, by various authorities, which neither accorded fully with each other or with those then obtained.

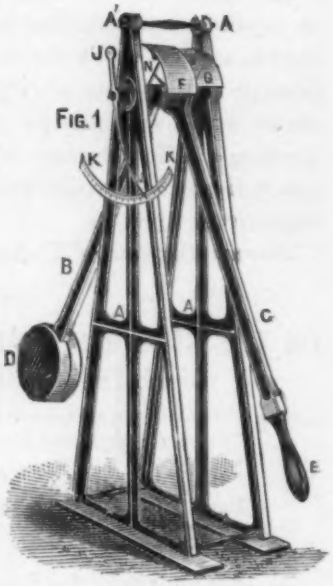
The desirability of determining how far these differences were due to errors of observation, and how far to variation in the quality of the materials examined, induced the writer to design several machines for the purpose of conducting with them a more extended and exact

* *Vide* Journal Franklin Institute.

series of experiments. The machine for measuring torsional resistance was furnished with an automatic registry, recording a diagram which is a reliable and exact representation of all circumstances attending the distortion and fracture of the specimen. No system of personal observation could probably be devised which could yield results either as reliable or as precise as such a system of autographic registry, and, as no method previously in use had given simultaneously, and at every instant during the test, the intensity of the distorting force and the magnitude of the coincident distortion, it was anticipated that the new method of investigation might be fruitful of new and, possibly, important results. This expectation, as will be seen, has been more than realized.

2. Description of the Apparatus.—The machine, as planned by the writer, and as built in the instrument makers' workshop, at the Stevens' Institute, is shown in Fig. 1. This form is that with which the investigations to be described were made. Since its construction, in 1872, however, some changes and improvements have been made in the design to adapt it to general work, and new designs have been made for special kinds of work, as for wire mills, railroad shops and bridge building.

Fig. 1



Two strong wrenches, C E, B D, are carried by the frames A A, A^1 A^1, and depend from axes which are both in the same line, but are not connected with each other. The arm, B, of one of these wrenches carries a weight, D, at its lower end. The other arm, C, is designed to be moved by hand, in the smaller machines, and by a gear and pinion, or a worm gear in larger forms of the apparatus. The heads of the wrenches are made as shown in Fig. 2, the recess, M, being fitted to take the head, on the end of the test pieces, which is usually given the form shown in Fig. 4.

Fig. 2

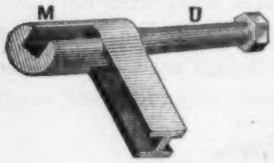


FIG. 3

FIG. 4

A guide curve, F, of such form that its ordinates are precisely proportional to the torsional moments exerted by the weighted arm, B D, while moving up an arc, to which the corresponding abscissas of the curve are proportional, is secured to the frame A A^1. The pencil holder, J, is carried on this arm, B D, and as the latter is forced out of the vertical position, the pencil is pushed forward by the guide curve, its movement being thus made proportionate to the force which, transmitted through the test piece, produces deflection of the weighted arm. This guide line is a curve of sines. The other arm, C E, carries the cylinder, G, upon which the paper receiving the record is clamped, and the pencil, J, makes its mark on the table thus provided. This table having a motion, relatively to the pencil, which is precisely the angular relative motion of the two extremities of the tested specimen, the curve described upon the paper is always of such form that the ordinate of any point measures the amount of the distorting force at a certain instant, while its abscissa measures the distortion produced at the same instant. The maximum hand, J, is sometimes useful as a check upon the record of maximum resistance.

The convenience of operation, the small cost,* and the portability of the machine are hardly less important to the engineer than the accuracy, and the extraordinary extent of information obtainable by it.

3. METHOD OF OPERATION.—The test piece having been given the shape and size which are found best suited for the purpose of the experiment, and to the capacity of the machine, it is placed in the jaws of the two wrenches, each of which takes one of its squared ends, and, a force being applied to the handle, E, the strain thrown upon the specimen is transmitted through it to the weighted arm, B D, causing it to swing about its axis until the weight exerts a moment of resistance which equilibrates the applied force. As the magnitude of the distorting force changes, the position of the weight simultaneously changes, and the pencil indicates, at each instant, the value of the stress upon the test piece. As the piece yields under

* Machines of the size of that used in these experiments, but of improved design, are made at the Stevens Institute, at prices as low as $150.

strains of increasing amount, also, the pencil is carried in the direction of the circumference of the cylinder on which its record is made, and to a distance which is proportional to the amount of distortion, *i. e.*, to the "total angle of torsion." As the applied force increases, the specimen yields, and finally, rupture occurring, the pencil returns to the base line, at a distance from the starting point which measures the angle through which the test piece yielded before its fracture became complete.

4. INTERPRETATION OF THE DIAGRAMS.—It has been shown that the vertical scale of the diagrams produced is a scale of torsional moments, and that the horizontal scale is one of total angles of torsion. Since the resistance to shearing, in a homogeneous material, varies with the resistance to longitudinal stress, it follows that the vertical scale is also, for such materials, a scale of direct resistance, and that, with approximately homogeneous substances, this scale is approximately accurate, where, as here, all specimens compared are of the same dimensions. Since the elasticity of the material is measured by the ratio of the distorting force, to the degree of temporary distortion produced, the diagrams obtained will exhibit the elastic properties of the material, as well as measure its ductility and its resilience.

Referring to the diagrams shown in the accompanying plates, it will be noticed that the first portion of the line is a curve of small radius, convex toward the axis of abscissas, and that the line then rises at a slight inclination from the vertical, but becoming very nearly straight, until, at a point some distance above the origin, it takes a reversed curvature. The first portion of the line is probably formed by the yielding of the loosely fitted packing pieces securing the heads of the specimen, and, after they have taken a bearing, by the early yielding, in some materials, of particles already overstrained. When a firm hold is obtained, the line becomes sometimes nearly straight, and the amount of distortion is seen to be approximately proportional to the distorting force, illustrating "Hooke's law," *Ut tensis sic vis.*

After a degree of distortion which is determined by the specific character of each piece, the line becomes curved, the change of form having a rate of increase which varies more rapidly than the applied force. When this change commences, it seems probable that the molecules, which, up to that point, retain generally their original distribution, while varying their relative distances, begin to change their positions with respect to each other, moving upon each other in a

manner similar, probably, to that action described by Mon. Tresca, and called the "Flow of Solids,"* and to which attention has already been called by Prof. J. Thompson.†

It is this point, at which the line commences to become concave toward the base, that *is considered to mark the "limit of elasticity."* It will be noticed that it is well defined in experiments upon woods, is less marked, but still well defined in the "fibrous" irons and the less homogeneous specimens of other metals, and becomes quite indeterminable with the most homogeneous materials, as with the best qualities of well worked cast-steel. This point does not indicate the first "set," since, as will be hereafter seen, a set is found to occur, either temporary or permanent, and usually partly temporary and partly permanent, with every degree of distortion, however small. It is at this "elastic limit" that the set begins to become considerable in amount and almost wholly permanent.

The inclination of the straight portion of the line from the vertical measures the *stiffness* of the specimen, the quantity $Cot.\ \theta = \frac{1}{Tan.\ \theta}$ being the ratio of the distorting force to the amount of distortion up to the "limit of elasticity." As it would seem from the results of experiment, as well as of deduction, that this rigidity is very closely, if not precisely, proportional to the hardness, in homogeneous substances, this quantity $Cot.\ \theta$ may be taken, for practical purposes, as a measure of the hardness of the metals, as well as of their elastic resistance to compression.

After passing the elastic limit, the line becomes more and more nearly parallel to the base line, and then, with the woods invariably, and in some cases with the metals, begins to fall rapidly before fracture becomes evident in the specimen. Where the rising portion of the line turns and becomes nearly parallel with the axis of abscissas, the viscosity of the material is such that the outer particles "flow" upon those within, and, while themselves still offering maximum resistance, permit molecules nearer the axis to also resist with approximately maximum force. It seems probable that, with the more ductile substances, nearly all are brought up to a maximum in resistance before fracture occurs, and this circumstance will be seen hereafter to have an important influence in determining the resistance to rupture. The hardest and most brittle materials break, with a snap,

* L'Ecoulement des Corps Solides; Paris, 1869, 1871.

† Cambridge and Dublin Mathematical Journal, Vol. III, 1848, pp. 252—266

before any such flow becomes perceivable, and before the line of the diagram commences to deviate, in the slightest degree, from the direction taken at the beginning, and before the approach to the elastic limit is indicated. It is evident that the standard formulas for torsional, as well as for other forms of resistance, cannot be perfectly correct, since they do not exhibit this difference in the character of the resistance offered by ductile and by rigid materials.

The *elasticity* of the material is determined by relaxing the distorting force, at intervals, and allowing the specimen to relieve itself from distortion so far as its elasticity will permit. In such cases, the pencil will be found to have traced a line resembling, in its general form and position, in respect to the coördinates, that forming the initial portion of the diagram, but almost absolutely straight, and more nearly vertical. The degree of inclination of this line indicated the elasticity, precisely as the initial straight line was made to give a measure of the original stiffness of the test piece, the cotangent of the angle made with the vertical, $Cot.\ \Phi = \frac{1}{Tan.\ \Phi}$ being the ratio of the force required to spring the piece through the range recoverable by elasticity, to the magnitude of that range. The fact, to be shown, that this value is always greater than $Cot.\ \theta$, for the same metal is evidence that more or less permanent set will always occur, and that the original stiffness of the specimen is always modified, whatever the magnitude of the applied force. The form of the line of elastic change indicates also the character of the molecular action producing it.

Finally, the form of the curve after passing the maximum, or after passing the point at which fracture commences, exhibits the method of variation of strength during the process of fracture. This portion is very difficult to obtain, with even approximate accuracy, with any but the toughest and most ductile materials. This terminal portion of the diagram would be, theoretically, a cubic parabola, the loss of resisting power varying with the progressive rupture of concentric layers, and the remaining unbroken cylindrical portion becoming smaller and smaller until resistance vanishes with the fracture of the axial line. In some cases, the curves obtained from ductile metals exhibit this parabolic line very distinctly. In all hard materials, the jar produced by the sudden rupture of surface particles is sufficient to separate those within, and the terminal line is straight and vertical.

The *homogeneity* of the material tested is frequently hardly less important than its strength, and it is very desirable to obtain evidence which may enable the experimenter to determine the value of tests of samples as indicative of the character of the lot from which the specimens may have been taken. If the specimens are found to be perfectly homogeneous, it may be assumed with confidence that they represent accurately the whole lot. If the samples are irregular in structure and in strength, no reliable judgment of the value of the lot can be based upon their character, and there can be no assurance that, among the pieces accepted, there may not be untrustworthy material which may possibly be placed just where it is most important to have the best. It is evident that the more homogeneous a material, the more regularly would changes in its resistance take place, and the smoother and more symmetrical would be the diagram. The depression of the line immediately after passing the elastic limit exhibits the greater or less homogeneousness of the material. The fact is illustrated in a striking manner in some of the curves presented, and we thus have—what had never, I believe, been before found—this method of determining homogeneousness.

The *resilience* of the specimen is measured by the area included within its curve, this being the product of the mean force exerted into the distance through which it acts in producing rupture, *i. e.*, it is proportional to the work done by the test piece in resisting fracture, and represents the value of the material for resisting shock. The area taken within the ordinate of the limit of elasticity, measures the capacity for resisting shock without serious distortion or injurious set.

The *ductility* of the specimen is deduced from the value of the total angle of torsion, and the measure is the elongation of a line of surface particles, originally parallel to the axis, which line assumes a helical form as the test piece yields, and finally parts at or near the point where the maximum resistance is formed. Its value is given on Plates II and III for each ten degrees of arc. Since, in this case, there is no appreciable reduction of section, or change of form, in the specimen, this value of elongation is our actual measure of the maximum ductility of the material, and is an even more accurate indication than the area of fractured cross section as usually measured after rupture by tension. It is to be understood that wherever comparisons are here made, without the express statement of other conditions, that specimens of the same dimensions are always represented in the diagrams.

5. Description of Illustrated Diagrams. The Woods.*—Plates I and II exhibit sets of curves which illustrate the general characteristics of a large number of materials, the first showing the peculiarities noted during experiments on the woods, and the second giving an interesting comparison of the metals.

The woods experimented upon were the following, the numbers of the respective curves on Plate I, indicating the material here correspondingly marked:

1. White pine (*Pinus Strobus*).
2. Southern pine (*Pinus Australis*), sap wood.
3. Southern pine, heartwood.
4. Black spruce (*Abies Nigra*).
5. Ash (*Fraxinus Americanus*).
6. Black walnut (*Juglans Nigra*).
7. Red cedar (*Juniperus Virginianus*).
8. Spanish mahogany (*Swietenia Mahogani*).
9. White oak (*Quercus Alba*).
10. Hickory (*Carya Alba*).
11. Locust (*Robinia Pseudo-acacia*).
12. Chestnut (*Castanea Vesca*).

The specimens were all of the form shown in Fig. 3, three and three-fourths inches long, with a diameter of neck of seven-eighths of an inch.

It will be noticed that, in all cases, at the commencement of the line, it rises, at a slight inclination from the vertical, and almost perfectly straight. This confirmation of Hooke's law, within the limit of elasticity, is best shown in the detached portion *a*, *a*, *a*, of the curve obtained with locust, in which the horizontal scale is somewhat magnified. The distortion is seen to be very precisely proportional to the distorting force, until the law changes at the limit of elasticity.

It will be observed that, in the larger number of cases, the torsional resistance increases with great regularity nearly to the angle of maximum stress where, suddenly, this rapid rate of increase ceases, and the limit of elastic resistance being passed, resistance diminishes rapidly with further increase of angular movement, until it becomes

*The section describing the woods is partly similar to that previously published in the "Journal of the Franklin Institute," and is here reprinted, *to preserve the present more elaborate treatise unbroken, and because the study of the several plates, and their comparison was considered essential to a thorough understanding of the subject.*—Ed.

zero. In the tougher and more dense varieties, this decrease of resistance occurs less slowly, and in some cases only disappears after a large angle of torsion is recorded. In the curves of exceptionally strong and tough woods, in which there is known to exist a great excess of longitudinal over lateral cohesion, as in those of black walnut 6, 6, locust 11, 11, and especially in those of hickory 10, 10, a peculiarity is perceivable which is somewhat remarkable, and which is especially important in a connection to be hereafter referred to at length.

In these instances the resistance is proportional to the amount of torsion, until a maximum is reached, the line then falls as torsion continues, until a minimum is passed, the curve then again rising and passing another maximum before finally commencing an unintermitted descent to the axis of abscissas. Where the difference between longitudinal and lateral cohesion is exceptionally great, the second maximum may, as illustrated, for example, by the line described in recording the test of hickory, have a higher value even than the first This interesting and previously unanticipated peculiarity was shown, by careful observation, to be due to the sudden yielding of lateral cohesion when the torsional moment reached the value indicated by the first minimum. The fibres being thus loosened from each other, this loose bundle of filaments yielded readily, until, by lateral crowding as they assumed a helical form and enwrapped each other, their slipping upon each other was gradually checked, and resistance again commenced increasing.

At the second maximum, yielding again began in consequence of the breaking of fibres under the longitudinal stress measured by that component of torsional force having a direction parallel with the filaments in their new positions, the exterior surface threads parting first under this tensile stress, and rupture progressing by the yielding of layer after layer, until the axial line being reached, resistance vanished. In this case, rupture seems never to occur by true shearing along one defined transverse plane. This feature of depression in the curve, occurring as described, is therefore the indication of a lack of symmetry in the distribution of resisting forces. It is evident that it may occur either by a difference in the value of cohesive force in the lateral and longitudinal directions, or by the structural defects of a specimen in which the substance itself may be endowed with cohesion of equal intensity in all directions.

The curves shown in Plate I exhibit well the relative values of these materials for the various purposes of the engineer.

White pine, 1, 1, 1, is shown by the considerable inclination of the line of stiffness from the vertical, to be soft and deficient in rigidity. The limit of elasticity is quickly reached, and the maximum resistance of the specimen is found at 15½ foot-pounds of moment. Rapidly losing strength after passing the limit of resistance, it is entirely broken off at an angle of 130°. The small area comprised by the diagram proves its deficiency of resistance, and its inability to sustain shock.

Yellow pine, 2, 2, 2, 3, 3, 3, far excels the first in all valuable properties shown by the curve. The sapwood seems, in the specimens tested, equally stiff with the heart, but it reaches the elastic limit sooner. The general form of the diagram is the same in both, and is characteristically different from that of the white pine. It evidently has great value wherever rigidity, strength, toughness and resilience are desired in combination with lightness, the latter most important quality, together with their cheapness, aiding the qualities here shown in determining the application of these woods so extensively for general purposes. It should be noted that, since all comparisons of strength are based on measures of volume, a comparison of densities should usually be obtained to assist the judgment in making a choice from among materials of which tests have been made.

Spruce, 4, 4, 4, while possessing far less stiffness than even white pine, excels it somewhat in strength, passing its maximum at 18 foot-pounds, and submitting to a torsion of nearly 200°. It is proven to possess proportionally greater resilience also. It is, however, far inferior to the yellow pine in every respect.

Ash, 5, 5, 5, is more deficient in strength and toughness than is generally supposed, and rapidly loses its power of resistance after passing the maximum, which point is found at about 27½ foot-pounds. These specimens may have been of exceptionally poor quality, or, possibly, were over-seasoned.

Black walnut, 6, 6, 6, is remarkably stiff, strong and resilient, its diagram resembling somewhat that of oak in general form and dimensions. The maximum of resistance reaches 35 foot-pounds, and the most ductile specimen was only broken off after yielding through an arc of 220°. Its stiffness is shown by the fact that it required a moment of 25 foot-pounds to spring it 10°, yellow pine requiring but 22 foot-pounds and spruce but 8, to give them the same amount of distortion.

Red cedar, 7, 7, 7, is very stiff, but is brittle and deficient in strength,

breaking off at 92°, and having a maximum power of resistance of but 20½ foot-pounds. It is, however, one of the stiffest of the woods, its specimen requiring 29 foot-pounds of torsional moment to produce a total angle of torsion of but 5°.

Spanish mahogany, 8, 8, 8, is both strong and stiff, bearing a stress of 44 foot-pounds, and requiring 32 to produce torsion of 10°.

White oak, 9, 9, 9, exhibits less strength than either good mahogany, locust or hickory, but it is exceedingly tough and resilient. Passing the maximum at an angle of 15°, under a torsional stress of 35½ foot-pounds, it retains its power of resistance nearly unimpaired up to about 70°, and then slowly yields until it suddenly gives way, after passing the angle 250°, under a strain due to 9 foot-pounds, and breaks off completely at 253°. This strength, toughness and endurance, under strains due to impact, may be attributed to its considerable lateral cohesion, and to the interlacing of its tenacious fibres, which gives this wood its "cross" grain.

Hickory, 10, 10, 10, has the highest maximum found during these experiments, the second of the pair of maxima already referred to being considerably above the maximum of locust even. This specimen exhibits well the well-known valuable properties of the material, requiring 45 foot-pounds to twist it 10°, reaching a limit of elasticity at 54 foot-pounds and 13°, and having a maximum resisting moment of 59½ foot-pounds. When it finally yields, it does so quite rapidly, breaking off at 145°.

Locust, 11, 11, 11, gives an excellent diagram. It is the stiffest of all, yielding but 10° at its maximum of 55 foot-pounds, and one piece, which was unusually hard and compact, requiring 48 foot-pounds to distort it 4°, and reaching a maximum angle of torsion of nearly 190°.

It was noticed, during this series of experiments, that different specimens of the same species of wood usually exhibited very nearly equal strength and rigidity, and that marked differences were only occasionally noted in elasticity and resilience.

6. The Metals, and the Curves produced by them.—Plate II* exhibits a series of curves which illustrate well the general characteristics and the peculiarities of representative specimens of the principal varieties of useful metals. In some cases two specimens have been chosen for illustration, of which one presents the average quality, while the other is the best and most characteristic of its class.

* See the Journal for May, 1874.

The diagrams obtained by testing metals are quite different in general character from those registered in experiments on the woods, yet there are some points of resemblance which it will be instructive to notice, since these similar characteristics indicate similar properties of the two materials, and a comparison aids greatly in the interpretation of the diagrams. The woods have a structure which differs, in a distinguishing degree, both in the distribution of the substance and in the action of these molecular forces capable of resisting rupture, from that of the metals, the latter being far more homogeneous, in both respects, than the former. Wood consists of an aggregation of strong fibres, lying parallel, or approximately so, and held together often by a comparatively feeble force of lateral cohesion. The latter force being, as often happens, destroyed, the mass becomes a collection of loose threads having the general character of a rope or cord, with slight or no twist. The metals, on the other hand, are naturally homogeneous, both in structure and in the distribution and intensity of the molecular forces. Well-worked and thoroughly annealed cast-steel, as an example, is equally strong in all directions, is perfectly uniform in its structural character, and is almost absolutely homogeneous as to strain. It would be expected, therefore, that the diagrams obtained by breaking such a material would differ from those of the woods, in having a smoother and more regular form, and this is shown to be actually the case by observation of the curves of cast-steel, cast-iron, bronze and others of the more homogeneous metals and alloys.

Some of the metals, it will be noticed, yield diagrams of less regular form. Wrought iron, as usually made, has a somewhat fibrous structure, which is produced by particles of cinder, originally left in the mass by the imperfect work of the puddler while forming the ball of sponge in his furnace, and which, not having been removed by the squeezers or by hammering the puddle ball, are, by the subsequent process of rolling, drawn out into long lines of non-cohering matter, and produce an effect upon the mass of metal which makes its behavior, under stress, somewhat similar to that of the stronger and more thready kinds of wood. In the low steels, also, in which, in consequence of the deficiency of manganese accompanying, almost of necessity, their low proportion of carbon, this fibrous structure is produced by cells and "bubble holes" in the ingot, refusing to weld up in working, and drawing out into long microscopic, or less than microscopic, capillary openings.

In consequence of this structure we find, as we should have anticipated, a depression interrupting the regularity of their curves, immediately after passing the limit of elasticity, precisely as the same indication of the *lack of homogeneousness of structure* was seen in the diagrams produced by locust and hickory.

The presence of internal strain constitutes an essential peculiarity of the metals which distinguishes them from organic materials. The latter are built up by the action of molecular forces, and their particles assume naturally, and probably invariably, positions of equilibrium as to strain. The same is true of naturally formed organic substances. The metals, however, are given form by external and artificially produced forces. Their molecules are compelled to assume certain relative positions, and those positions may be those of equilibrium, or they may be such as to strain the cohesive forces to the very limit of their reach. It even frequently happens, in large masses, that these internal strains actually result in rupture of portions of the material at various points, while in other places the particles are either strongly compressed, or are on the verge of complete separation by tension. This peculiar condition must evidently be of serious importance, where the metal is brittle, as is illustrated by the behavior of cast-iron, and particularly in ordnance. Even in ductile metals it must evidently produce a reduction in the power of the material to resist external forces. This condition of internal strain may be relieved by annealing hammered and rolled metals, and by cooling castings very slowly, in order that the particles may assume, naturally, positions of equilibrium. In tough and ductile metals, internal strain may be removed by heating to a high temperature and then cooling under the action of a force approximately equal to the elastic resistance of the substance. This process, called "Thermo-tension," was first used by Professor Johnson in the course of his experiments as a member of a Committee of the Franklin Institute, in 1836,* and the effect of this action in apparently strengthening the bars so treated, was stated in the report of the committee. The fact that this effect was very different with different kinds of iron was also noted, but it does not appear that the cause of this, which they term "an anomalous" condition of the metal was discovered by them.

Metals which are very ductile may frequently be relieved of internal strain, also, by simply straining them while cold to the elastic

* Journal Franklin Institute, 1836–7.

limit, and thus dragging all their particles into extreme positions of tension, from which, when released from strain, they may all spring back into their natural and unstrained positions of equilibrium. This fact, which does not seem to have been previously discovered by investigators of this subject, will be seen to have an important bearing upon the resisting power of materials, and upon the character of all formulas in which it may be attempted to embody accurately the law of resistance of such materials to distorting or breaking strain.

Since straining the piece to the limit of elasticity brings all particles subject to this internal strain into a similar condition, as to strain, with adjacent particles, it is evident that indications of the existence of internal strain, and through such indications a knowledge of the value of the specimen, as effected by this condition, must be sought in the diagram, before the sharp change of direction which usually marks the position of the limit of elasticity is reached. As already seen, the initial portion of the diagram, when the material is free from internal strain, is a straight line up to the limit of elasticity. A careful observation of the tests of materials of various qualities, while under test, has shown that, as would, from considerations to be stated more fully hereafter, in treating of the theory of rupture, be expected, this line, *with strained materials, becomes convex towards the base line*, and the form of the curve, as will be shown, is parabolic. The initial portion of the diagram, therefore, determines readily whether the material tested has been subjected to internal strain, or whether it is homogeneous as to strain. This is exhibited by the *direction* of this part of the line as well as by its form. The existence of internal strain causes a loss of stiffness, which is shown by the deviation of this part of the line from the vertical to a degree which becomes observable by comparing its inclination with that of the line of elastic resistance, obtained by relaxing the distorting force —*i. e.*, the difference in inclination of the initial line of the diagram and the lines of elastic resistance, *e*, *e*, *e*, indicates the amount of existing internal strains.

Forged Iron.—In Plate II, the curves numbered 6, 1, 22 and 100 are the diagrams produced by three characteristic grades of wrought-iron. The first is a quality of English iron, well known in our market as a superior metal. The second is one of the finest known brands of American iron, and the third is also of American make, but it does not usually come into the market in competition with well-known

irons, in consequence of the high price which is consequent upon the necessary employment of an unusual amount of labor, in securing its extraordinarily high character.

No. 6 at first yields rapidly under moderate force, only about 50 foot-pounds of torsional moment being required to twist at 5°. It then rapidly becomes more rigid, as the internal strains, so plainly indicated, are lost in this change of form, and at 6° of torsion, the resistance becomes 60 foot-pounds, as measured at *a*. Here the elastic limit is reached. The next 3° produce no increase of resistance. The fact shows that this iron, which was not homogeneous as to strain, is also not homogeneous in structure. We conclude that it must be badly worked and seamy, and that it may have been rolled too cold; the former is the probable reason of its lack of homogeneous structure, the latter gave it its condition of internal strain. After the first 9° of torsion, resistance steadily rises to a maximum, which is reached only when just on the point of rupture, and the piece finally commences breaking at 250°, and is entirely broken off at 285°. Its maximum elongation, whose value is proportionable to the reduction of section noted with the standard testing machines, is 0·691. The terminal portion of the line, after rupture commences, is not usually accurate as a measure of the relation of the force to the distortion. The increase of resistance between the angle 9° and the angle of rupture is produced by the additional effort in resistance due to the "flow" or drawing out of particles, as already indicated, and the precise effect of which will be noticed at length in a succeeding section relating to the theory of rupture.

Applying the scale for tension, which in the case of these curves was very exactly 24,000 pounds per square inch for each inch measured vertically on the diagram, we find that the elastic limit was passed under a stress equivalent to a tension of 19,800 pounds per square inch, and that the ultimate tenacity was 59,200 pounds per square inch. When nearly at the maximum the specimen was relieved from stress, the pencil descending to the base line, and the elasticity of the piece produced a certain amount of recoil. The angle intercepted between the foot of this nearly vertical line, *c*, and the origin at *O*, measures the *set*, which is almost entirely permanent. The distance measured from the foot of the perpendicular, let fall upon the axis of abscissas, from the head of this line to the foot of the line *e*, measures the elasticity, *and is inversely proportional to the modulus.* A comparison of the inclination of the line made by the pencil in

reascending, on the renewal of the strain with the initial line of the diagram, gives the indication of the amount of internal strain originally existing in the piece.

It will be noticed that the horizontal movement of the pencil is recommenced at *I*, under a higher resistance than was recorded before the elastic line was formed. In this case the piece had been left under strain for some time before the stress was relieved, and the peculiarity noted is an example of an increase of resistance under stress,* or more properly of *the elevation of the elastic limit*, of which more marked examples will be shown subsequently.

The exceptional stiffness and limited elastic range here shown, as compared with the other examples given, is probably a phenomenon accompanying and due to this increase of resistance under stress.

Examining No. 1 in a similar manner, we find that it is far freer from internal strain than No. 6, its initial line being much more nearly straight and rising more rapidly. It is rather less homogeneous in structure, and is forced through an arc of 6°, after having passed its elastic limit, before it begins to offer an increasing resistance. It is evidently a better iron, but less well worked, and, as shown by the position of the elastic limit, is somewhat harder and stiffer. No. 1 retains its higher resistance quite up to the point at which No. 6 received its incidental accession of resistance by standing under strain, and the two pieces break at, practically, the same point, No. 1 having slightly the greater ductility. When the "elastic line," *e*, is formed, just before fracture, it is seen that No. 1 has a greater elastic range and a lower modulus than No. 5. It should be observed that the line by which the pencil *descends* to the base line has usually no value, owing to the fact that no care is generally taken to remove the stress as gradually as it is applied. When such care is taken, the lines are usually coincident, and do not form the loop here seen. It will also be noticed that these lines often cross each other, that on the right being the important line. The elastic line formed by No. 1 at between 40° and 45° of torsion is seen to be very nearly parallel with that obtained near the terminal portion of the diagram, and illustrates the fact here first revealed to the eye, that *the elasticity of the specimen remains practically unchanged up to the point of incipient rupture*, and this fact corroborates the deductions of Wertheim* and others who came to this conclusion from less

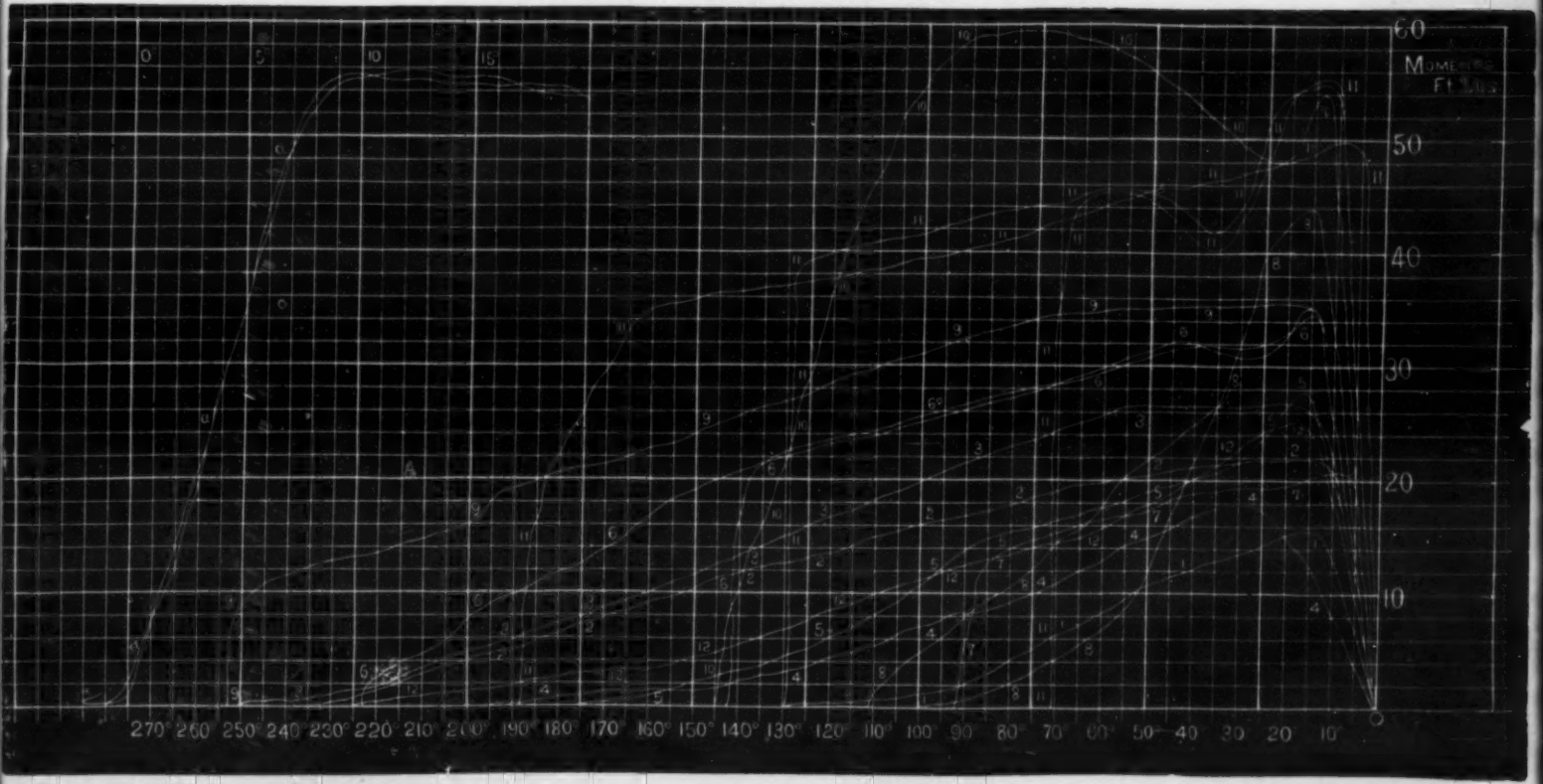
* *Vide* Transactions, Vol. II, page 290.

Journal Franklin Institute, Vol. LXVII. Investigations of the Resistance of Materials. Plate I.

AUTOGRAPHIC STRAIN—DIAGRAMS OF WOODS

PRODUCED BY THE

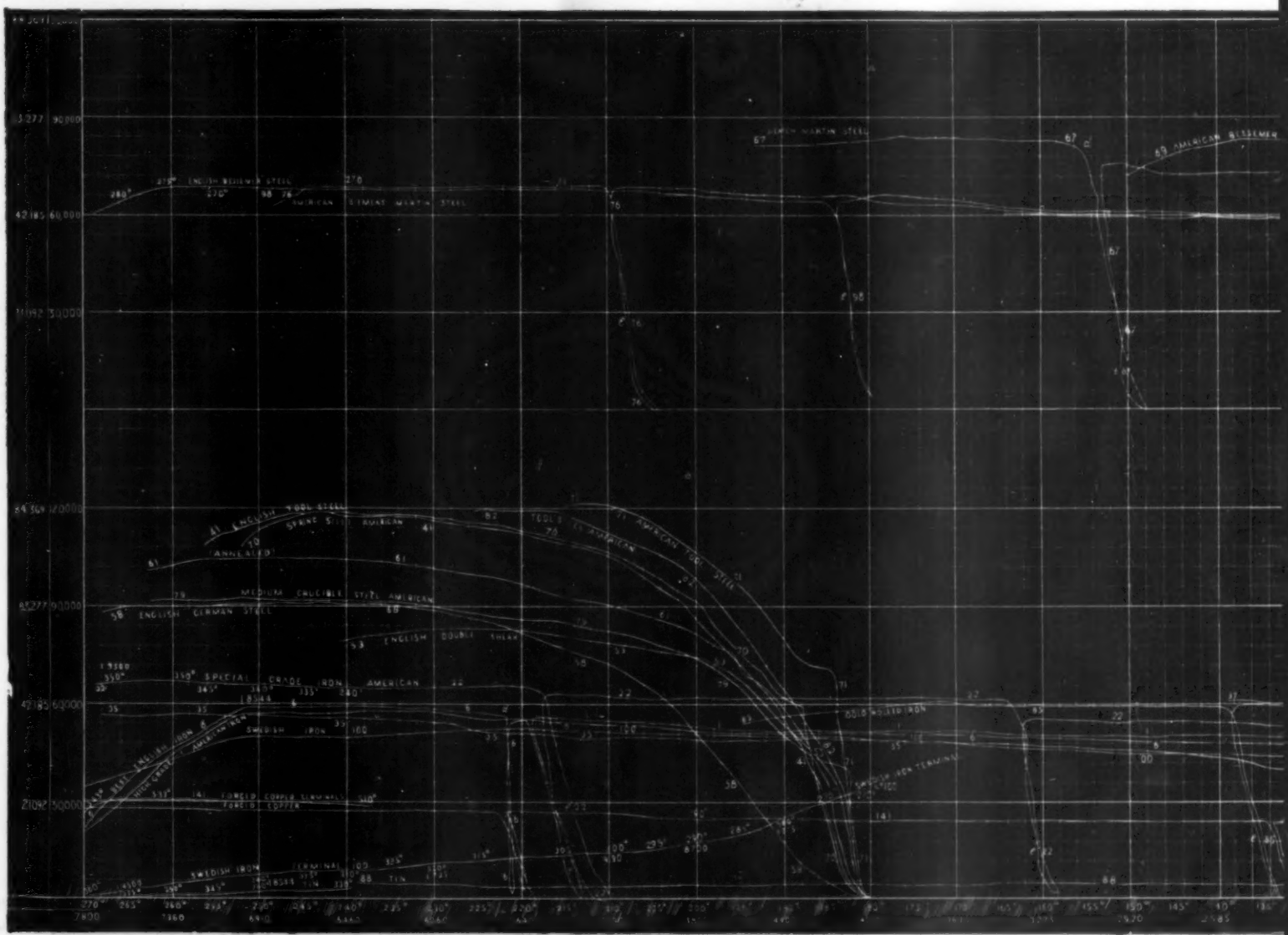
Testing Machine of PROF. R. H. THURSTON.



AUTOGRAPHIC STRAIN—

PRODUCED B

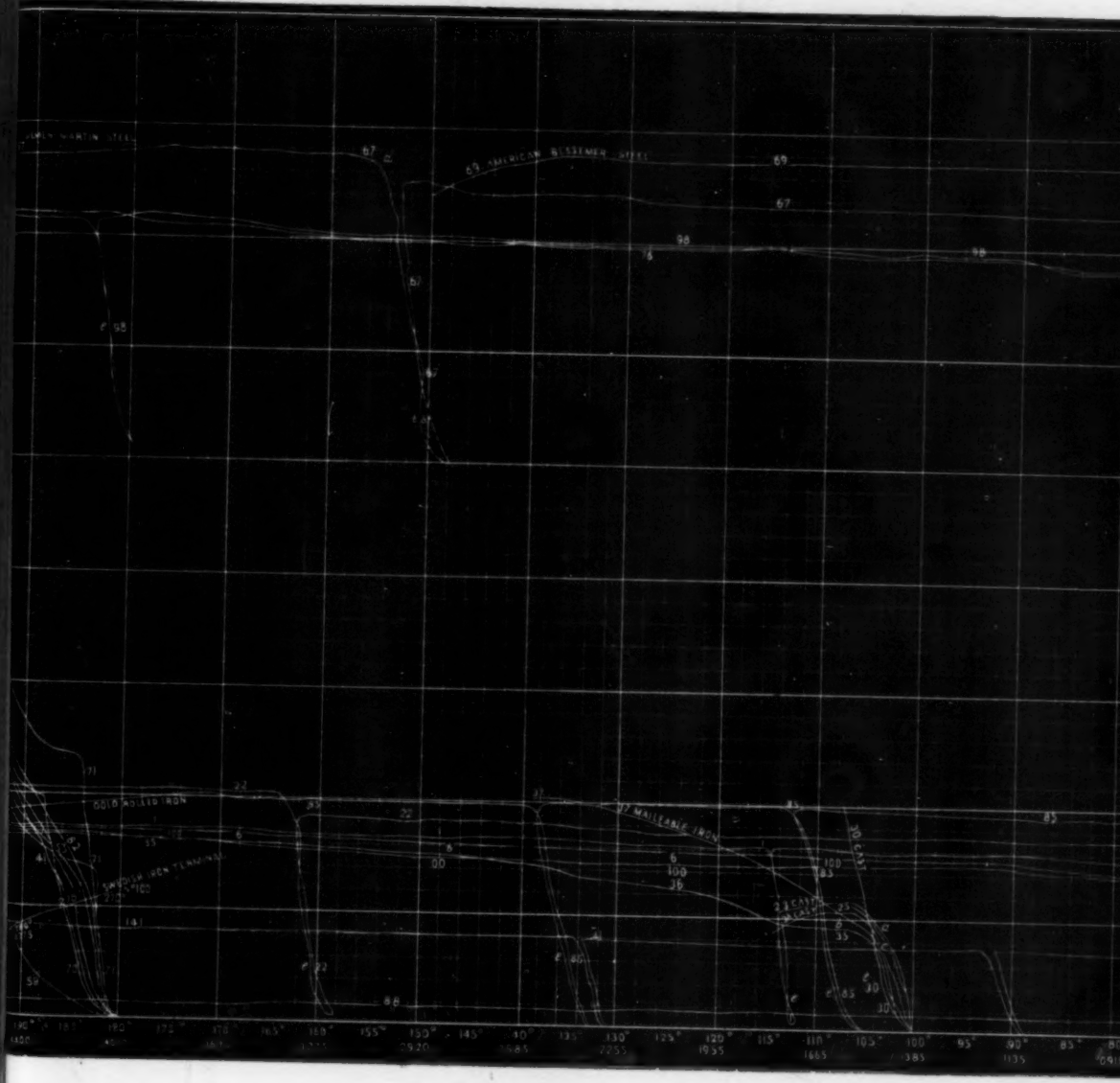
TESTING MACHINE OF PROF



AUTOGRAPHIC STRAIN-DIAGRAMS OF META

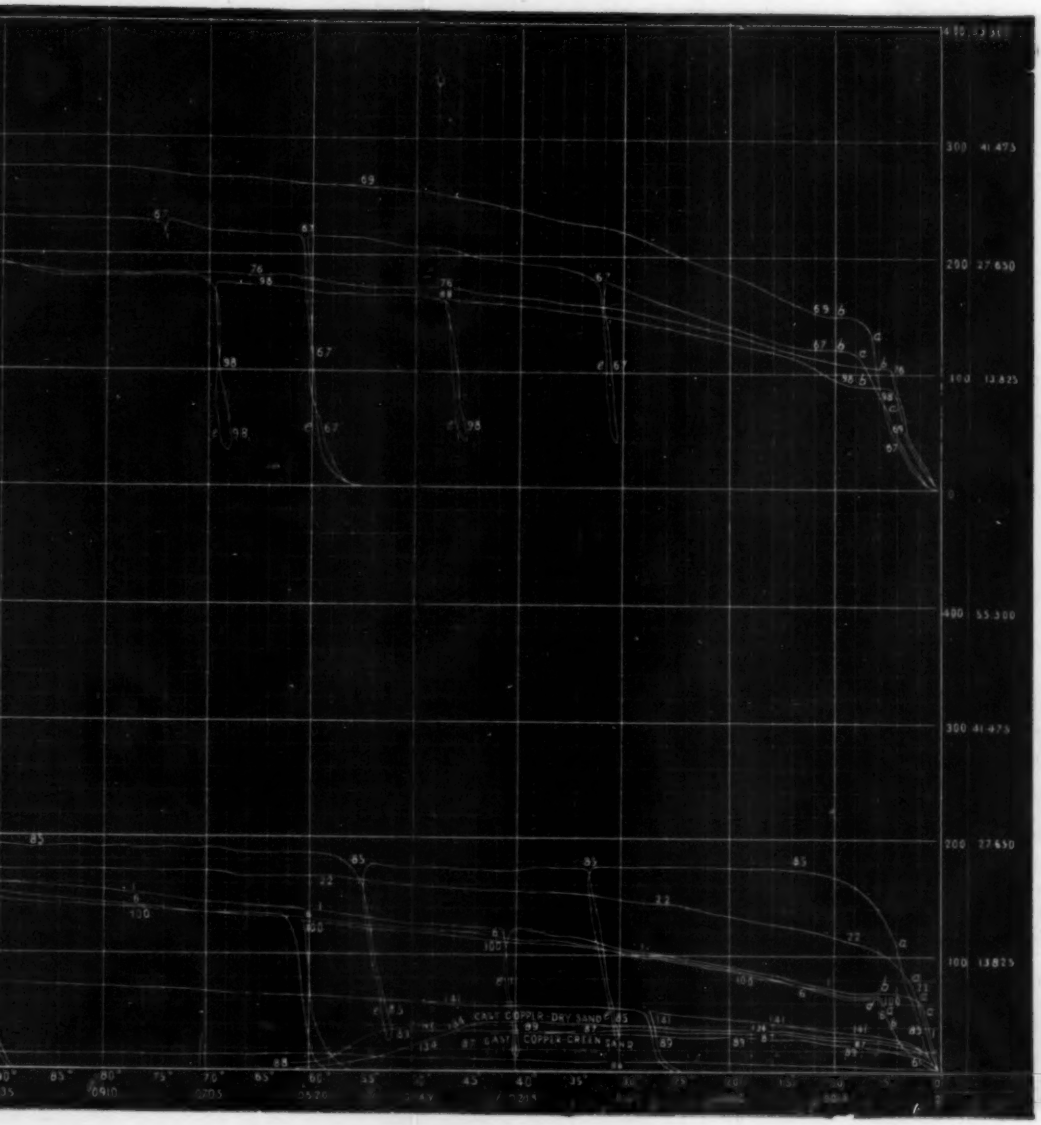
PRODUCED BY THE

TESTING MACHINE OF PROFESSOR R. H. THURSTON.


69 AMERICAN BESSEMER STEEL
67
69
67
98
98
GOOD ROLLED IRON
77 MALLEABLE IRON
22 CAST IRON
100
100
100
85
85
85

Torsional Moments.

Foot-Pounds.	Kilogram-metres.



Angle of Torsion.

Elongation.

satisfactory modes of research. All experiments yet made give a similar result.

No. 22 illustrates the characteristics of a metal which probably represents one of the best qualities of wrought iron made in this or in any other country, and with which every precaution has been taken to secure the greatest possible perfection, both in the raw material and in its manufacture. The fact that it finds a market at sixteen cents a pound proves that even such care and expense are well applied. The line of this diagram, starting from *O*, rising with hardly perceptible variation from its general direction, turns, at the elastic limit, *a*, under a moment of about 80 foot-pounds, equivalent to a tension of about 24,000 pounds per square inch; and with between 2° and 3° of torsion only, and thence continues rising in a curve almost as smooth and regular as if it had been constructed by a skilful draughtsman. Reaching a maximum of resistance to torsion of 220 foot-pounds and an equivalent tensile resistance of over 66,000 pounds per square inch, at an angle of 345°, it retains this high resistance up to the point of rupture some 358° from its starting point. The maximum elongation of its exterior fibres is 1·2, making them at rupture 2·2 times their original length. This would produce a probable breaking section in the common testing machine equal to 0·4545 of the original section.†

From the beginning to the end this specimen exhibits its superiority, in all respects, over the less carefully made irons, Nos. 1 and 6, which, it should be remembered, are themselves deservedly known as good brands. The homogeneousness of No. 22 is almost perfect, both in regard to strain and to structure, the former being indicated by the straightness of the first part of the diagram and its parallelism with the "elastic line," *e*, produced at 217½°, and the latter being proven by the beautiful accuracy with which the curve follows the parabolic path indicated by our theory as that which should be produced by a ductile homogeneous material. At similar angles of torsion, No. 22 offers invariably much higher resistance than either Nos. 1 or 6, and this superiority, uniting with its much greater ductility, indicates an immensely greater resilience. It is evident that for many cases, where lightness combined with capacity to carry live

* *Vide* Annales de Chimie et de Physique.

† Compare Kirkaldy: Strength of Iron and Steel; pp. 111, 135, for reduction in Yorkshire and Swedish bars. The elongation there given has, of course, no value as a measure of ductility.

loads and to resist heavy shocks are the essential requisites, this iron would be by far preferable, notwithstanding the cost of its manufacture, to any of the cheaper grades. Comparing their elasticities, as shown at 210°, 215°, it is seen that No. 22 is about equally stiff and elastic with No. 1, while both have a wider elastic range and are less rigid, and hence are softer than No. 6, whose elastic line is seen at 221°. All of the characteristics here noted can be accurately gauged by measuring the diagrams, and constants are readily obtained for all formulas, as illustrated in a later section of this paper, in which the construction of formulas and the determination of constants will be made the subject of investigation.

No. 100 is the curve obtained from a piece of Swedish iron, marked . Its characteristics are so well marked that one familiar with the metal would hardly fail to select this curve from among those of other irons. Its softness and its homogeneous structure are its peculiarities. Its curve, at first, coincides perfectly with that of No. 6. It has, however, slightly less of the condition of internal strain, and a somewhat higher limit of elasticity. The elastic limit is found at $5\frac{1}{2}°$ of torsion, and at a stress of 65 foot-pounds of moment, equivalent to 19,500 pounds on the square inch, in tension. Its increase of resistance, as successive layers are brought to their maximum and begin to flow, is very nearly the same as that of the specimens Nos. 1 and 6, and the line lies between the diagrams given by these irons up to 30°, and then falls slightly below the latter. At 220°, it attains a maximum resisting power, and here the outer surface begins to rupture, after an ultimate stretch, of lines formerly parallel to the axis, amounting to 0·564. Had this elongation taken place in the direction of strain, as in the usual form of testing machine, it would have produced a reduction of section to 0·64, the original area.* At this point the stress in tension equivalent to the 176 foot-pounds of torsional stress, is 52,800 pounds per square inch. From 250° the loss of resistance takes place rapidly, but the actual breaking off of the specimen did not occur until it had been given a complete revolution. This part of the diagram distinguishes the metal from all others, and shows distinctly the exceptionally tough, ductile and homogeneous character which gives the Swedish irons their superiority in steel making. No. 22, even, although much more extensible, is harder than No. 100, and yields more suddenly when it finally gives way.

* Compare Styffe; Strength of Iron and Steel; p. 133, Nos. 26—30.

A comparison of the results here recorded with those obtained by Styffe,* will afford a good basis upon which to form an idea of the accuracy as well as the convenience of this method of deriving them. An examination of the broken test piece gives some evidence confirmatory of the record. The exterior surface of the twisted portion has an appearance intermediate between that of No. 1, Fig. 5,† and No. 22, Fig. 7, with an evident tendency to "kink." The surface of fracture is lighter and more lead-like than even No. 22, and its "fibre" is finer and texture more plastic in appearance. It is beautifully uniform in character. On one end of this specimen, where a piece had been nicked and then broken off by a sharp blow, the absence of all fibrous appearance, and the granular texture and magnificently fine, regular grain are very marked, and indicate that the material is entitled to its established position as the purest metal known in the market. The specimens themselves furnish almost as valuable information, after test, as the diagrams contain, and should always be carefully inspected with a view to securing additional or corroborative information. Fig. 5 is a sketch of specimen No. 1, and shows its somewhat granular fracture, and the seamy structure produced by a defective method of working. Fig. 6, from specimen No 16, more nearly resembles that which gave the diagram marked 6. The metal is seen to be good, tough, and better in quality than No. 1, but it is even more seamy, and even less thoroughly worked, as is evidenced by the cracks extending around the neck, and by the irregularly distributed flaws seen on its end.

Fig. 5.

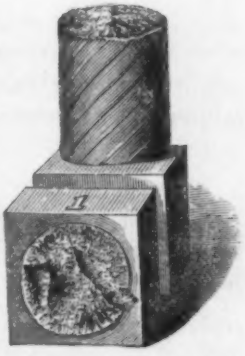


Fig. 6.

No. 7 exhibits the appearance of No. 22 after fracture, and shows,

* As on last page.

† From an article in the "Scientific American," of January 17th, 1874, on Testing the Quality of Iron, Steel and other Metals without Special Apparatus.